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A Review on Low Power Efficiency Improvement in the Dual Active Bridge Converter Using Flyback Mode for Bidirectional Photovoltaic Micro-Inverter

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Abstract—this paper focuses on the photovoltaic micro-inverters with integrated battery storage. The topology which is used in dc-dc converters is dual active bridge which provides bidirectional power flow. At low power level the efficiency is low and the regulation achieved is also not satisfactory. So, in order to achieve those, a modified DAB converter is used. With the modification of one switch it can operate as two-transistor fly back. For the optimal performance of DAB converter a DC link voltage in the two stage micro inverter can be adjusted dynamically. The scheme which is Dual mode control is analyzed theoretically and it shows the improvement in the converter efficiency at low power level.

***Keywords*— Dual active Bridge, Photovoltaic micro inverters, isolated dc-dc converter**

1. INTRODUCTION

The use of fossil fuels like coal, petroleum (crude oil) and natural gas contributes to the many climatic changes and these cannot be formed so easily like as they being consumed .Hence, the alternate is to use the renewable sources like solar, wind etc and there is a great popular support for the use of renewable sources which can harness electricity without any emissions of carbon dioxide.

Harnessing electricity from these will depend on the cost and efficiency of technology used which is constantly improving in order to reduce costs per kilo watt, and per kWh at the source. Due to the intermittent nature of Solar and Wind backup capacity is required.

Many policies are set to support the renewable, prioritize and subsidies them in grid systems and some 50 countries have these provisions. Utilizing these energies require battery or storage capacity.

The World bank group and the United Nations have committed to sustainable energy for all initiative which is reinforced by sustainable Development Goal7 which says ensure access to affordable, reliable, sustainable and modern energy for all .

An estimated 171 TWH of off grid electricity will need to be generated by 2030 which is equivalent to 100GW power of photo voltaic. In the small scale photovoltaic based grids intermittent nature of PV, load shedding is quite challenging.

DC-DC micro converters [1] and AC-DC micro inverters [2] provide high granularity Maximum Power Tracking (MPPT) [3] at substring level which leads to increased robustness to clouds, dirt and ageing effects, irradiance.

Solar micro inverter is a device which is used in PV that converts direct current generated by a single solar module to alternating current and these are different from conventional string inverter.

The solar micro inverter which is connected to each single PV panel and the output from several micro inverters can be combined and often fed to the electrical grid.

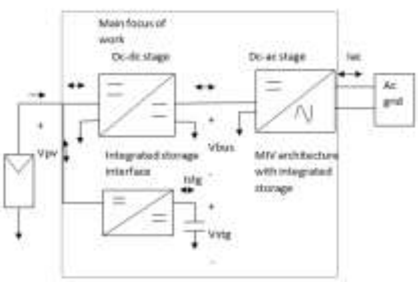

Fig1 Two stage micro inverter with integrated storage interface

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The micro inverters has several advantages over conventional inverters one is they can isolate panels electrically so small amounts of snow, shading, on any solar module does not disproportionately reduce the outcome of the entire array for its connected solar module. By performing maximum power point tracking (MPPT) each micro inverter harvests optimum power.

The energy storage system is essential for islanded operation for micro inverter which is a bidirectional ac-dc converter which is interfaced with battery bank or a flywheel [4].

For high efficiency interfacing the low voltage dc storage either batteries or ultra capacitors directly connected to the PV bus. Lithium ion ultra capacitor which offers high specific energy has conventional electric double layer capacitors.

2. TWO MODES OF OPERATION AND ARCHITECTURE

The proposed dc-dc architecture is shown in figure (2).This converter is a modified DAB that interfaces V_{pv} with the dc link V_{bus}

DAB MODE:

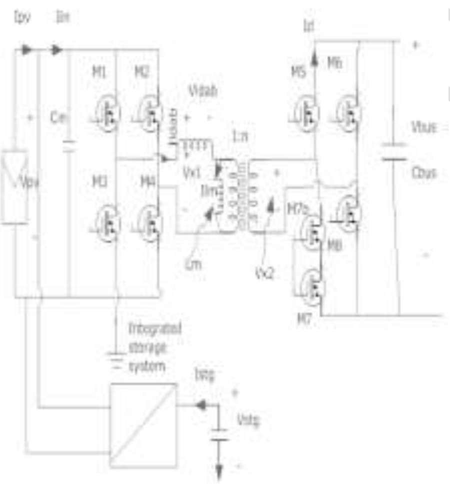

Fig2 Modified DAB circuit for improvement in efficiency at low power

The use of renewable energy is limited due to the intermittent nature of its output. So, in order to compensate that variation energy storage systems are used .To control the power flow a bidirectional dc-dc converter is generally needed between storage energy and load. A Dual active bridge is a bidirectional dc-dc converter with identical primary and secondary side bridges interfaced through a high frequency transformer, dc link capacitors and energy transfer inductor which enables the power flow in both directions.

The DAB topology was selected based on

a) Galvanic isolation

b) Soft switching operation

c) Simple phase shift power control

The DAB topology is bidirectional as the stored energy is used to transfer power to the grid and it can also take from the grid.

V_{bus} is generally maintained a fixed voltage by inverter stage in two stage micro inverter and DAB achieves turn on Zero Voltage Switching (ZVS),maximum efficiency when $V_{bus}= nV_{pv}$ and the circulating current is also minimized [5] and the reference voltage V_{bus*} is chosen to optimize efficiency at the nominal operating point [6].

In order to minimize the losses in the DAB V_{bus} is dynamically adjusted in the inverter stage so that $V_{bus*}=nV_{mpp}$ where V_{mpp} is photo voltaic maximum power point voltage and V_{mpp} undergoes less fluctuations in a typical day

Flyback mode: The conventional DAB converter suffers from relatively poor efficiency at low power level and a PV generator spends more operating time below 50% of its rated power due to the switching and drives losses [5] whose operation is based on frequency optimization [5].

Hence in order to overcome that by making some modification in the DAB configuration we can improve efficiency.

The switches M1 and M4 remain active, M8 is kept on and all other switches are off and the secondary side switch is modified by adding one switch to achieve bidirectional blocking capability in flyback mode.

The flyback mode operated with fixed on time in pulse frequency modulation [7].

Vol11,Issue2,FEB/2020
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$$T_{on}=D_1T_s$$

Where D_1 is the duty cycle in flyback mode

T_s is the switching period

The 2T flyback topology has many advantages over DAB mode at low power level which has lower switching and gate drive losses and the body diodes of M2 and M3 maintain the drain voltage on M1 and M4 which leads to the reduction in electromagnetic interference and reduces the blocking voltage rating on primary side switches to V_{pv}.

There are two inherent limitations in 2T flyback topology they are

a) To avoid transformer saturation D_1 must be less than 50%

b) V_{bus} must be less than nV_{pv} to ensure the power transfer to V_{bus} from the body diode M5.

L_{dab} which results in soft turn on of the output diode in 2T flyback topology as the energy captured in this inductor is transferred back to the input unlike the conventional flyback scheme.

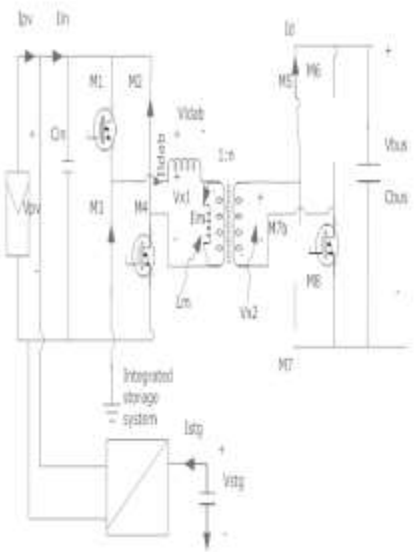

Fig 3 Switch configuration of flyback mode

The flyback mode exhibits unidirectional power flow and by adding another switch reverse power flow can possible but the DAB mode is sensitive to conduction losses at low voltage level.

The DAB mode can be prevented from operating in this condition by adopting burst mode control instead a slightly lower efficiency than flyback mode.

3. Dual mode control:

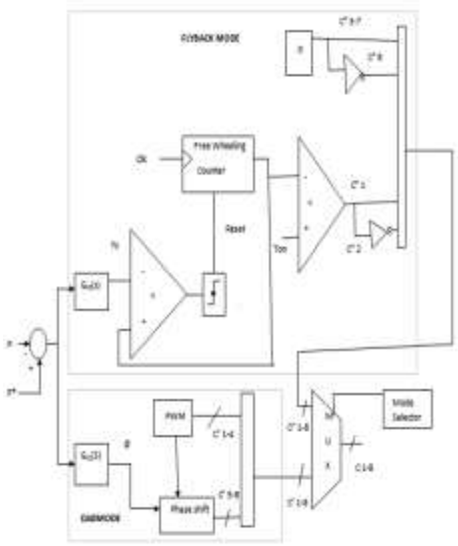

Fig 4 Dual mode control

The DAB mode is adopted if p is higher than a threshold value or p is negative

Here Ø is controlled to regulate he power flow to and from the inverter stage while the state of charge and MPPT operation can be controlled by the dedicated interface converter.

In flyback mode controller adjusts T_s in order to regulate p to p*.Here assuming magnetizing inductance of transformer L_m is larger than L_{dab}.

4. REGULATION ANAYSIS AND TRANSFORMER DESIGN: The input power of the converter is regulated in two modes and the analysis states the improvement in regulation is greatly seen in flyback mode at low power levels.

It shows that the regulation accuracy is worse at low power level in the DAB mode. In the flyback mode the converter operates with variable switching frequency .The incremental power in fly back mode has the opposite compared to DAB mode as the rate of change in power is less at low power levels which improves the accuracy of the power regulation loop.

The transformer designed for dual mode operation is shown in fig (5).The 3C95 Ferrite material has low core losses up to 100°C. Here gap less core is assumed in transformer in DAB mode exhibits the magnetic flux density which is independent of the power level and it is designed to limit the core losses at the rated power and maximum frequency which results in the saturation flux density of material when above B_{peak}.

In this case it is possible to increase T_{on} significantly higher than predefined for the flyback operation at low power and low frequency without resorting to a gapped core.

The maximum on time suggested is 1.28μs, hence the core operates with a significantly higher B_{peak} in flyback mode.

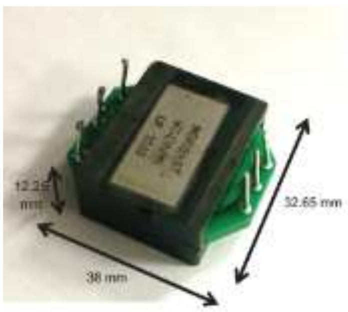

Fig 5 Planar Transformer used in Dual mode operation

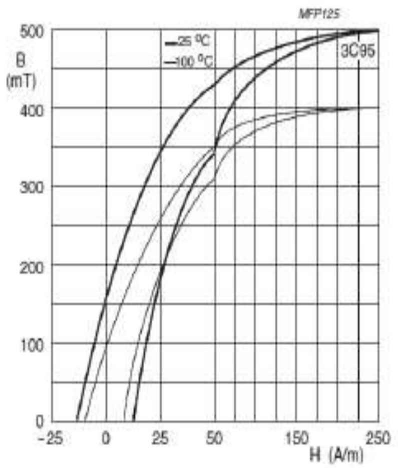

Fig 6 Typical B-H curve for magnetic material

5. EFFICIENCY ANALYSIS:

In order to evaluate the threshold reference power value, $P_{threshold}$ an approximate loss analysis is useful.

In this we discuss the dominant power losses in the DAB and flyback modes. The loss analysis includes conduction losses, switching losses, core losses. The comparison for loss analysis for these two modes is below

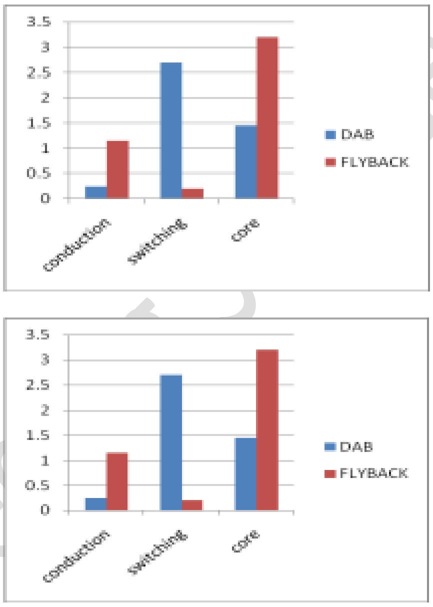

Fig 7 Theoretical analysis of power losses for a) P=10W b) P=40W

The loss breakdown is calculated theoretically for P=10w and P=40w.The conduction losses in all active and passive elements are lumped together.

The switching losses also include the drive losses. Due to the higher B_{peak} and f_s the core losses increases rapidly with the power. The transformer and inductor core losses are slightly higher in flyback mode and the switching losses are reduced by at least 10 times by eliminating the turn off losses on the high voltage side at the cost of marginal increase in conduction loss. In DAB core losses remain almost constant over the full phase shift range due to constant Lm excitation.

Conclusion:

A novel DAB switching scheme was introduced for the dc-dc stage for photo voltaic applications which is the modified DAB called as fly back mode which exhibits higher efficiency than the DAB mode at the cost of an additional switch. The switching losses are reduced greatly in fly back mode due to the less switching actions and reduced frequency but the core and the conductions losses are more than DAB. Hence the fly back mode achieves higher accuracy in power regulation for low power levels compared to DAB mode resulting in more stable operation.

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