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A Modified Aalborg Inverter for Grid Connection and Renewable Energy Application

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Abstract – This paper proposes a topology for a two stage dc/ac inverter which is suitable for grid connection of renewable energy sources. This new inverter combines the operation of both CSI and VSI. The main advantage is that only one power stage works at high frequency to achieve minimum switching loss. The conventional Aalborg inverter is realized using a dual supply and suitable for a range of 150V to 350V of input dc voltage. This range of voltage may not be available from renewable energy source. Here single power supply is used in which input voltage can vary from 30V. Hardware prototype for 500W/50Hz is designed and implemented.

I INTRODUCTION

Nowadays, energy crisis is the major issue which the world faces. The power resources are being extinct due to large power demand. An alternative for the power resources are renewable energy such as photovoltaic cell, wind energy, tidal energy etc. Inverters can be mainly categorized as CSI and VSI where VSI is dominant over CSI in grid tied application. This is because CSI must have a large inductor as a storage element and to keep the current constant for proper modulation while VSI does not require this. The main challenge for CSI is to decrease the total dc link inductance and then the efficiency can be improved. Various inverter topologies are available and the problem is with the switching losses because all the power stage operates at high frequencies. This can cause the system to be less efficient. This issue can be solved by operating only one power stage at high frequency. In renewable energy system input voltage to the converter may vary greatly due to the change in environmental conditions. Photovoltaic system is one of the main methods to make use of solar energy. This energy can be utilized for a distributed generation system which can be interconnected to the grid with the use of certain power electronic converters or inverters. It is well known that the output of a photovoltaic cell is direct current, and in order to interface the generated power to the grid it is required to connect power electronic converters and inverters to make it suitable for the grid connection. A grid tied inverter is most commonly used to transform the available energy to grid. The irradiance level will not be same at all times, it varies time to time and also with the climatic conditions. So to keep the input voltage of the inverter to a definite range a front end converter with high frequency switching is mostly used to boost up the voltage. Many inverters were proposed for the grid connection. A transformerless single phase non isolated inverter for ac module application is proposed for in [2]. This is suitable for both grid connection and solar pane requirements. But it is a two stage topology and requires higher cost and complex control. An active non-linear modulation technique to reduce lo order harmonics in CSI is presented in [3]. This paper also deals with the reduction of dc inductance value. A Z source inverter is proposed in [4] which overcome the technical limitations of VSI and CSI. It acts as a buck boost inverter hence the need for a two stage inverter is reduced. A dual mode time sharing cascaded sinusoidal inverter is proposed in [5]. It consist of a time sharing buck type current fed converter and time sharing sinusoidal pulse modulated full bridge inverter. But the switching frequency of this inverter is high compared to the conventional ones. A boost- buck converter based PV inverter is proposed in [6], where boost cascaded with a buck converter is designed. In this paper a new modified Aalborg half bridge inverter is proposed with a single power source in which input voltage can vary from 40V onwards. The operating principle is explained for both positive and negative half cycle. Both the half cycles works in symmetry. The major attraction for this inverter is that it can works as both CSI and VSI. The control loops for the inverter is designed separately for both buck and boost control. This paper is organized as follows. Section II describes the existing models of grid tied inverters. Section III composed of the working and principle of operation of Aalborg inverter. Section IV deals with the modified Aalborg inverter circuit and its advantages. Section V explains the control loop of the proposed inverter. Section VI describes the hardware part of the inverter followed by conclusion in section VII.

II EXISTING TECHNOLOGIES

Various inverter topologies are available to connect with the grid connected system. Mostly used ones are VSI and CSI.

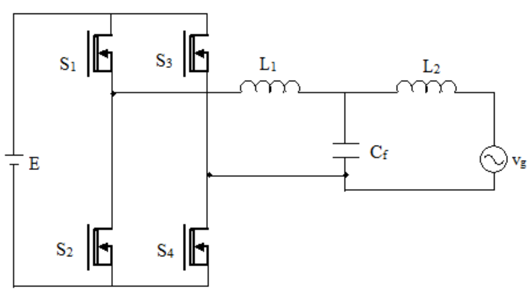

Fig. 1. Single phase grid tied VSI

Fig 1 shows a typical VSI with an LCL filter at the end [1]. It is understood that VSI is a step down or a buck type inverter. So that this type of inverter is used in application where the amplitude of input voltage should be higher than the grid voltage.

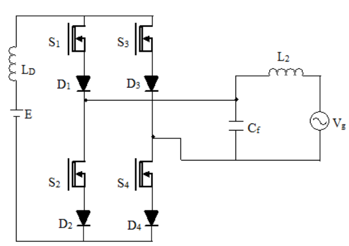

Fig. 2. Single phase grid tied CSI

Fig 2 shows the typical connection of CSI to the grid tied system [1]. CSI is basically a step up or boost inverter and it is only used in the cases where the amplitude of the input voltage is lower than the grid voltage.Usually the output from a renewable source such as PV may vary in a big range so this CSI or VSI cannot be directly connected to the grid. For connecting this we need an additional dc-dc converter in front of inverter so that input voltage can meet the grid requirement. But it is a less efficient method because both stage works at high frequency.

III CONVENTIONAL AALBORG INVERTER

The schematic layout of an Aalborg inverter is shown in Fig 4.

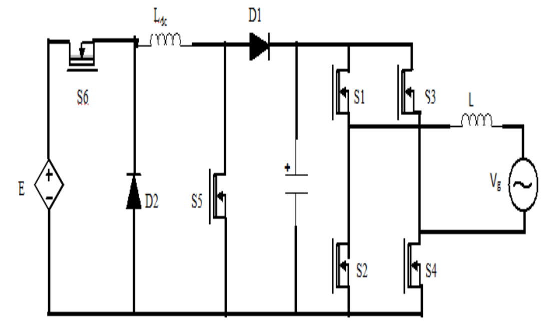

Fig. 4. Full bridge Aalborg inverter

Fig 4 shows the full bridge Aalborg inverter, which has two stages and output stage works at line frequency and only one power stage works at high frequency. Total inductance in the loop is low so conduction power loss is reduced. Proper working of this inverter is explained through a half bridge Aalborg inverter.

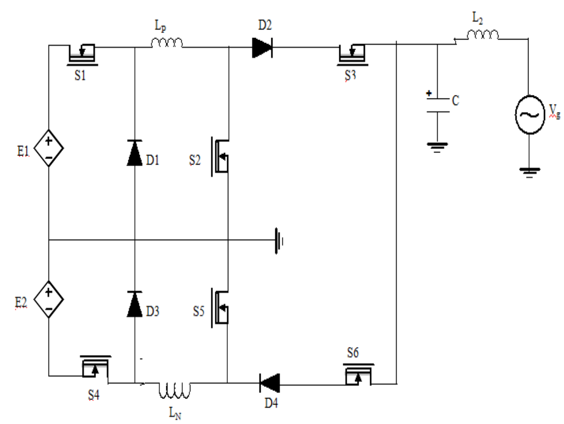

Fig. 5. Half bridge Aalborg inverter.

This inverter works in both buck and boost mode according to value of input voltage. If the amplitude of the input voltage is greater than the grid voltage then it works as a buck converter or VSI and if the amplitude of the input voltage is lower than the grid voltage then it operates as boost converter or CSI. The principle of operation is explained in two modes.

Mode 1: E1 or E2 greater than Vg

This is the case when the input voltage is greater than or equal to the grid voltage. There are two cases during one cycle of grid voltage i.e. positive half cycle and negative half cycle. During the positive half cycle E1 provides total supply for the circuit.

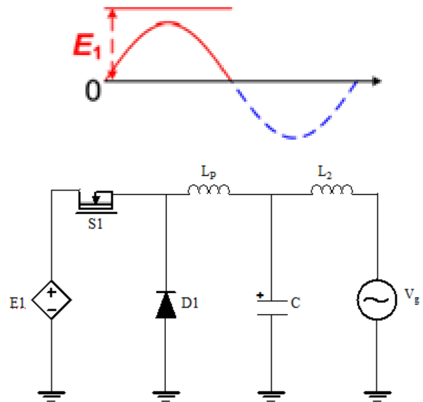

Fig.6. Equivalent circuit when E1 or E2 > Vg

In this mode switches S3 is ON, S2 is OFF and S1 operates at high frequency to obtain a perfect sinusoidal grid current. From the Fig.6 it is clear that the inverter act as a pure buck converter with an LCL filter at the end. This filter is capable of satisfying the harmonic requirements of the grid. Similarly is the case in negative period of grid voltage which is shown in Fig. 7.

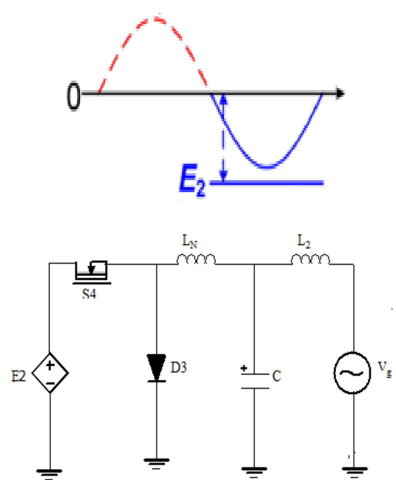

Fig. 7. Equivalent circuit during negative half cycle

In this mode E2 supplies the total energy for the circuit. This mode comes into action when the amplitude of input voltage is higher than the grid voltage. Here switches S6 is ON, S5 is OFF and S4 works at high frequency. This works as pure VSI with LCL filter at the end.

Mode 2: E1 or E2 less than Vg

If the amplitude of input voltage is less than the grid voltage then the inverter should operate as boost inverter. Here the control becomes little complex because inverter should perform the operation of both buck and boost according to the input voltage. The time sequence is split into six intervals. Time sequence during positive half cycle is shown in Fig 8.

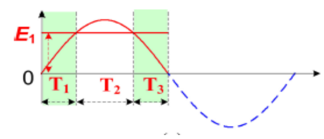

Fig. 8. Working sequence when E1 or E2 less than Vg

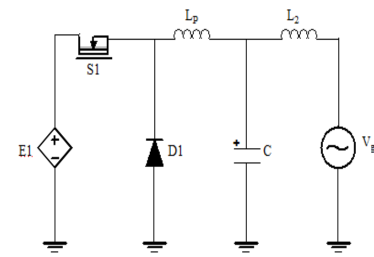

Fig. 9. Equivalent circuit during T1 and T3

During T1 and T3 the input voltage E1 is greater than grid voltage, so this should act as a pure VSI. Hence the switch S3 is ON, S4 works at high frequency and all other switches are in OFF condition. Now, during the interval T2 the amplitude of input voltage is lower than that of the grid voltage, so the inverter should operate as a boost converter. The equivalent circuit in this mode is shown in the Fig.10.

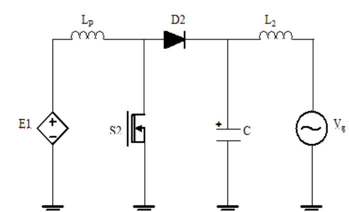

Fig.10. Equivalent circuit of time interval T2

In this interval switches S1 and S3 are ON and S2 operates at high frequency. From the circuit it is clear that the inverter acts as pure CSI with a CL filter at the end. In the negative half cycle the operation is similar and time sequence is shown in Fig. 11.

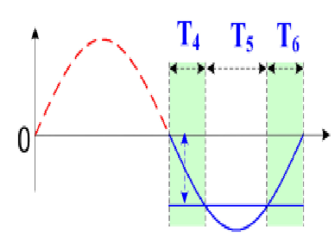

Fig. 11. Working sequence of negative half cycle during Mode 2

During T4 and T6, input voltage is lower than the grid voltage so it should act as buck converter. The equivalent circuit is shown in Fig. 12.

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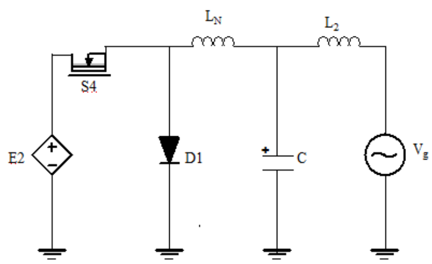

Fig.12. Equivalent circuit during T4 and T6

From this figure it is clear that it is pure VSI connected to the grid with an LCL filter. Switch S6 is ON and S4 works at high frequency, rest of the switches are OFF. During T5, the input voltage is lower than the grid voltage. And the inverter should operate as a CSI.

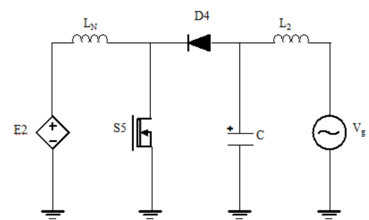

Fig.13. Equivalent circuit during T5

Fig. 13 shows the equivalent circuit during the time interval T5 and it is a pure CSI with CL filter connected to the grid. Here three switches are in ON condition. S4 and S6 is ON, S5 works at high frequency.From the previous analysis it is understood that in all modes only one switch operate at high frequency and improves the efficiency by reducing the switching loss .Conventional Aalborg inverter has the advantage of low switching losses by operating only one switch at high frequency. It can operate both as CSI and VSI so there is no need of any separate converter. It is designed such that the input dc voltage is assumed to vary from 150V to 300V. This inverter is mainly designed for the application of renewable energy source to the grid. But in practice high voltage range of 150V to 300V cannot be obtained from renewable energy sources, so an additional converter may be required most of the time. Then Aalborg inverter is designed with a dual supply, but realizing this in hardware is difficult.

IV MODIFIED AALBORG INVERTER

To overcome the disadvantages of the conventional Aalborg inverter a separate supply circuit is designed. Modified Aalborg inverter is designed in a way which has only one power supply. This single power supply circuit is split into two voltages with equal amplitude and acts as dual supply. These voltages can be treated as E1 and E2 in the conventional Aalborg inverter. Thus the working of modified circuit remains the same as that of the conventional inverter.

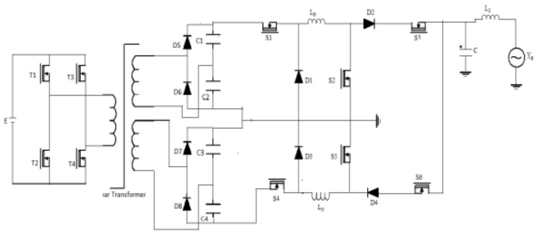

Fig. 14. Circuit diagram of Modified Aalborg inverter

Fig.14 shows the schematic circuit of the modified Aalborg inverter consisting of only one power supply. The single power supply is divided into two separate dc sources using a simple push-pull circuit. The input voltage of this modified circuit can vary from 40V onwards. This input voltage can be boosted to thrice its value by changing the turn's ratio of the transformer. Therefore dual voltage of equal amplitude is obtained and it is equal to the working range voltage of conventional Aalborg inverter. This modified circuit is well suited for the application of renewable energy resources. For example output voltage from photovoltaic panel can vary according to the temperature conditions. At times it provides only low voltage such as 40V etc. For this PV panel to be connected to the grid modified Aalborg inverter is well suitable.

V CONTROL LOOP

For controlling the buck and boost switches in both half cycle a separate control method have been designed [8]. The control circuit is shown in Fig. 15.

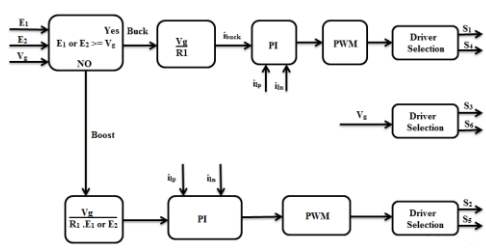

Fig. 15. Control diagram

The input signals to the control loops include the input dc voltages E_1 and E_2, the grid voltage Vg and the inductor currents i_{lp} and i_{ln}. The control loop works by comparing the dc voltage and the grid voltage. If the input voltage is higher

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than the grid voltage then the buck control loop works. In buck control loop boost switches will be OFF. The reference current is derived as

$$Iref_{buck} = \frac{|v_g(t)|}{R_f} \qquad (1)$$

whereR_f is the equivalent resistor. This reference current is given to PI controller. This PI controller checks for the steady state error between reference current and the inductor current. This error is further provided to PWM generator which produces the necessary PWM to drive the buck switches S_1 and S_4. Similar is the case in boost control loop.If the input voltage is lower than the grid voltage the control becomes little complicated and an indirect current control loop is adopted. The reference current can be derived as

$$Iref_{boost} = \frac{|V_g(t)|^2}{R_f.\ E_1/E_2} \qquad (2)$$

This reference current is given to the PI controller which checks the steady state error between reference current and inductor current. This error is processed to the PWM generator and produces necessary PWM to switch the boost switches S_2 and S_5. Switches S_3 and S_6 are low frequency switches which is directly been switched from the reference grid voltage.

VI EXPERIMENTAL SETUP

In order to verify the design theoretically a 220V/50Hz/500W inverter prototype is designed and realized using a TMS320F28027F piccolo microcontroller. The switches in the inverter are realized using MOSFETs. MOSFETs used in the inverter part are IRF840 and the MOSFETs used in the dual supply circuit are P80NF55. For the dual supply circuit the controller used is dsPIC30F2010. From the dual supply circuit two equal dc voltages are obtained. The photograph of the prototype is shown in Fig. 16.

Fig 16. Photograph of the experimental setup

The parameter values are calculated and tabulated and is shown in Table 1

Table 1:Design Parameters

PARAMETER	VALUE
L_1, L_2	6.6Mh
C	2μF
F_S (S_1,S_2, S_4, S_5)	25kHz

Two cases are analyzed when the input voltage of the Aalborg inverter is greater than grid voltage and is less than grid voltage.

Case 1: E1 or E2 is greater than Vg

In this case the input voltage to the dual supply circuit is set as 35V which produce a dual equal voltage at its output as 250V which is higher than the grid voltage. This dual voltage is given as input to the inverter circuit. Hence the buck control loop works properly. The resultant waveform is obtained in DSO and is shown in fig 17.

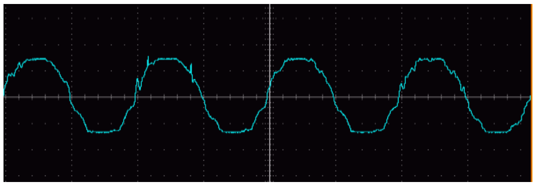

Fig. 17. Voltage waveform in buck mode

Case 1: E1 or E2 is greater than Vg

In this case the input voltage to the dual supply circuit is set as 20V which produce a dual equal voltage at its output as 110V which is less than the grid voltage. This dual voltage is given as input to the inverter circuit. Hence the boost control loop works properly. The resultant waveform is obtained in DSO and is shown in fig 18.

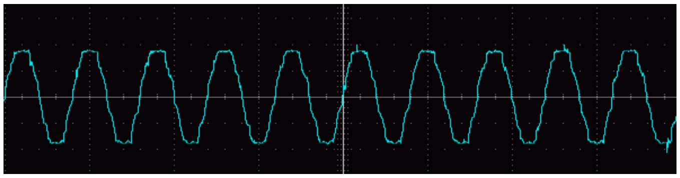

Fig .18. Voltage waveform in boost mode

From the resultant waveforms it is clear that the voltage waveform is purely sinusoidal having a 50Hz frequency and is equal in amplitude of the grid voltage.

VII CONCLUSION

The proposed inverter combines the operation of both CSI and VSI according to the variations in the input voltage. This inverter is mainly suitable for renewable energy resources. The input dc voltage range can vary from 30V by making it to single supply by using a push pull circuit. Switching losses is

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reduced since only one switch operates in high frequency. Efficiency is higher because only one switch operates at higher frequency during a power stage.

REFERENCES

[1]"Weimin Wu, JunhaoJi, and FredeBlaabjerg "Aalborg Inverter—A New Type of "Buck in Buck,Boost in Boost" Grid-Tied Inverter" IEEE Transactions on Power Electronics, Vol. 30, No. 9, September 2015

[2]D. Meneses, F. Blaabjerg, O´ .Garc´ıa, and J. A. Cobos, Trans. Power Electron., vol. 28, no. 6, pp. 2649–2663,Jun. 2013.

[3]R. T. H. Li, H. S. H. Chung, and T. K. M. Chan, "An active modulation technique for single phase grid connected CSI," IEEE Trans.Power Electron., vol.22, no.4,pp. 1373-1382, Apr. 2007.

[4]F.Z. Peng, "Z-source inverter," IEEE Trans. Ind. App., vol.39, no. 2, pp. 504-510, Mar/Apr. 2003.

[5]W.Wu and T. Tang, " Dual mode time sharing cascaded sinusoidal inverter," IEEE Trans. Energy Convers., vol. 22, no. 3, pp. 795-797,sep.2007.

[6]Z. Zhao, M. Xu, Q.Chen, J. Lai, and Y. cho, " Derivation , analysis, and implementation of a boost-buck converter based high efficiency PV inverter." IEEE Trans. Power Electron., vol. 27, no. 3, pp. 1304-1313, Mar.2012.

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