Soft Switched AC-Link Wind Power Converter

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***Abstract*— A novel soft switched ac-link buck-boost converter for high power ac-ac wind power conversion is proposed. This configuration uses two bi-directional switches per leg of the converter resulting in a 12 bi-directional switch topology. Power transfer is accomplished via a link inductor which is first charged from the input, then discharged to the output with a precisely controllable current PWM technique which results in near zero harmonics at all frequencies below twice the link frequency, as there are two power transfers for each link cycle. Capacitance in parallel with the link inductor produces zero-voltage switching for both turn-on and turn-off.**

I. Introduction

Full power converters to interface the variable voltage and frequency of permanent magnet synchronous generators as used in wind turbines are increasingly being used, both in order to readily supply the reactive power needed to stabilize the utility grid, and to support the grid during faults that cause low grid voltage. A common topology for achieving this is the four quadrant capable PWM voltage sourced converter, which draws current with low harmonics from the generator, boosting low generator voltage as needed, and delivering the power with low harmonics and commanded power factor to the utility lines. While this topology is quite effective, it has a few drawbacks, such as subjecting the generator to severe du/dt transients, requiring a large and inefficient output filter, and requiring an isolation transformer between the output and the utility as needed to prevent common mode voltages from appearing on the generator windings.

We discuss below an alternate topology that accomplishes the same function as the above described four quadrant VS converter, but which largely avoids its drawbacks.

II. Development of AC Link Converters

High frequency link power conversion has been employed very successfully in dc-dc converters [1-4], which have demonstrated the advantages and also possible difficulties in working with high frequency links. Problems were associated with circuit topologies and also device capabilities. The use of resonant circuits in high frequency dc-dc converters has since been reported [5]. Ac-ac and dc-ac converters employing high frequency ac links have also been reported in [6-9]. Most of these converters are designed for specific type of source/loads. Reference [10] reports a resonant link voltage sourced topology that provides one-step bidirectional power conversion for different kinds of loads/sources. This configuration uses twelve bidirectional switches and employs Pulse Density Modulation (PDM) as a means to control the currents. The use of PD results in an integral number of fixed period voltage pulses to the input and output which produces a wide range of ripple frequencies which may cause resonances with any input/output filter. Other resonant link voltage sourced topologies that make use of twelve unidirectional switches, by providing a dc offset to the ac link, have also been suggested. Reference [11] proposes a pulsed current source topology with a partial resonant link and twelve unidirectional switches, without the dc offset. However, it is limited in operation response due to its inability to supply output current at low voltages or power factors, at link frequencies sufficiently high to avoid input/output filter resonances. Also, there is a large dead time due to the resonant 'flyback' which reduces the power capability by about 30%. This largely negates its advantage of using a lower numbers of switches compared to the proposed topology.

III. Proposed Topology

Figure1 shows a schematic of the proposed pulsed current sourced, partial resonant link topology, in which all power transfer goes through the link inductor in a completely indirect means. Each leg of the converter is made of 2 bidirectional switches, realized by anti-series IGBT/diodes' for the 25 kW prototype that is nearing completion. SGCTs or IGBTs rated to 5500 V or more could be used for medium voltage (2300 VAC and up) high power applications. Series operation of switches as needed for voltages greater than 2700 VAC is made simple by the soft switching. An inductor-capacitor pair is used to form the partial-resonate ac link.

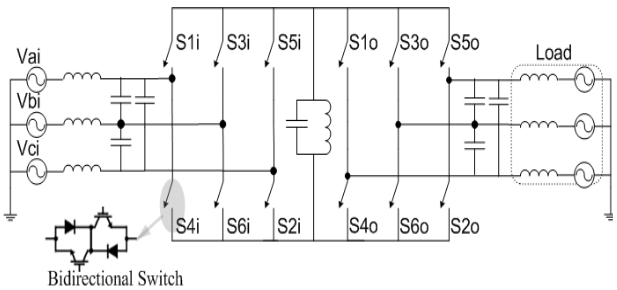

Fig. 1 Proposed Topology Schematic

This completely symmetric converter operates by first charging the link from the capacitance buffered inputs and then discharging the stored energy to the buffered output, with any voltage ratio between input and output allowed. During the charging modes, the link current rises to a peak value determined by the amount of power to be transferred. Charging is done via two input phase pairs (Modes I and III) which are nominally the lines having the highest and the second highest instantaneous voltages (for unity power factor). The charged link discharges into two output phase pairs similar to the inputs. Charging (discharging) currents are controlled by nanosecond increments to produce precisely the correct charging (discharging) so as to eliminate all harmonics below the power cycle frequency, which is twice the link frequency. Partial resonance occurs between the power transfer modes. During the partial resonant modes, appropriate switches are enabled and turn on as they become forward biased, as with a diode, resulting in low turn-on losses. The link capacitor results in low-loss soft turn-off of the switches, with no additional losses due to this snubber. Reverse turn-off is with low rates of current reversal, with the resulting low recovery current buffered by the link capacitor, which gives very low reverse recovery losses. The low overall switching losses allow the use of slower and higher current density switches, possibly with soft switched optimized structures, or alternatively, higher link frequencies, or an optimal combination thereof. As evident from the simulation results in the next section, for a given link current direction, the voltage changes are all in the same increasing or decreasing direction, and hence all switching is soft.

Figure 2 shows the basic operating modes while figure 3 shows the relevant converter waveforms. The converter is essentially current sourced, although all link current flows are AC. The reader may refer [12] for a detailed explanation of the topology.

At no time is the output directly connected to the input and hence there is a measure of isolation between the two, allowing for transformer-less operation with the neutral points of both input and output grounded, thereby eliminating offset common-mode voltages. Additionally, full galvanic isolation between input and output may be achieved by using a transformer version of the link inductor with dual, interleaved windings.

A shielded air-core inductor is being used in the IEEE 519 compliant 25kW three phase to three phase prototype motor drive which weighs less than 10 lbs, with less than 14 lbs for the input line reactance, as compared to over 140 lbs for other 25 kW IEEE 519 compliant drives. This drive may be used as is as a wind power converter, as the topology is symmetric and may buck or boost in either direction. Converters of this topology for wind power applications that have much higher power ratings will use even lower per unit weight self shielded toroidal air core reactors. Link capacitance may be advantageously added to buffer turn-off losses, with the optimal capacitance determined by balancing reduced turn-off losses against the resulting slight decrease in power throughput. The input/output line filters are composed of compact film capacitors with a small line reactor on the utility side.

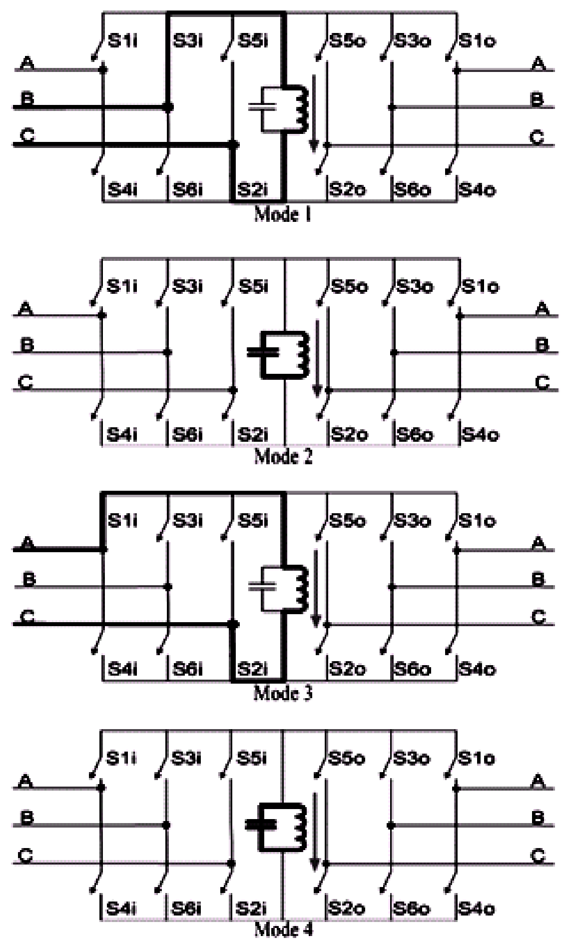

Fig. 2 Basic operating Modes

An important feature of the converter that makes it very suitable for wind power applications is its ability to perform buck or boost operations, allowing it to operate to or from any voltage level and/or power factor within the voltage and current constraints of the converter. Thus it can boost a generator's output, with unity power factor and low harmonics, to the utility interface voltage, at any power factor being demanded by the utility. Its ability to change voltage levels between the input and output is due to the partial resonant period between the charging and the discharging modes (Mode IV). During this mode, the charged link is simply allowed to resonate. With this, the link voltage can rise to values higher than the input voltage, the level restricted only by the capacitive loading of the LC link. Turning on the output switches at the desired voltage level allows any input-output voltage ratio. To drive into low output voltages and/or power factors, and to keep the link frequency sufficiently above the input/output filter resonances, excess link energy may be returned back to the input.

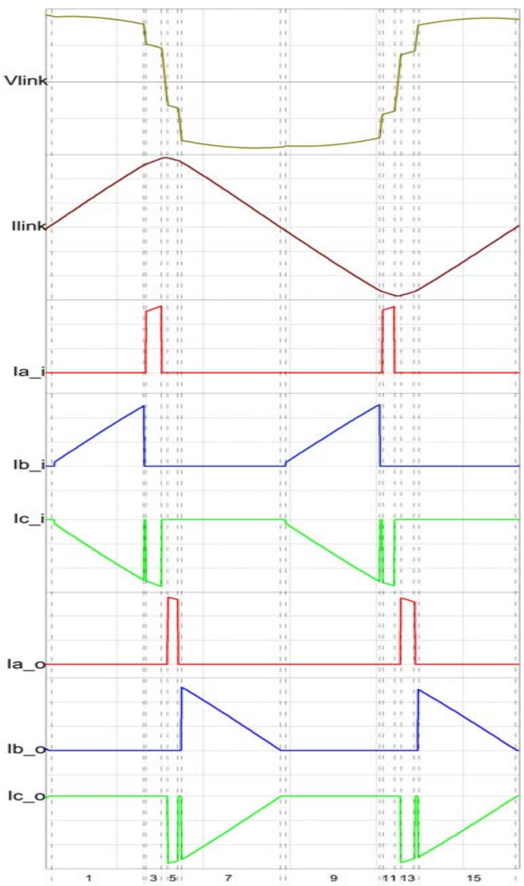

Fig. 3 Relevant converter waveforms

IV. SIMULATION RESULTS

Initial ideal device simulation results of the converter are presented below. The simulation parameters are presented in table XX. Input was at three phase line-to-line 2300 V (RMS), 60Hz and power level is 2 MW. The switches used were ideal and bi-directional. Input current ripple and harmonics as shown in figure 4 are shown to be very small. The link voltage and current waveforms are shown in figure 5 and figure 6 respectively. This Inverter can also be used to boost the voltage. Filtered Input and Output Voltages for the boost case are shown in Figures 7 and 8 respectively. In this case the Input source frequency is 30Hz. Figure 9 represents the link Voltage for this case.

Figure 10 shows the 25kW prototype in development.

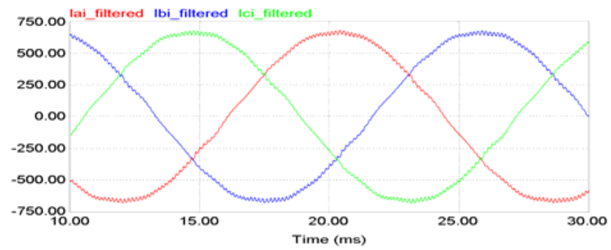

Fig. 4 Input Line currents

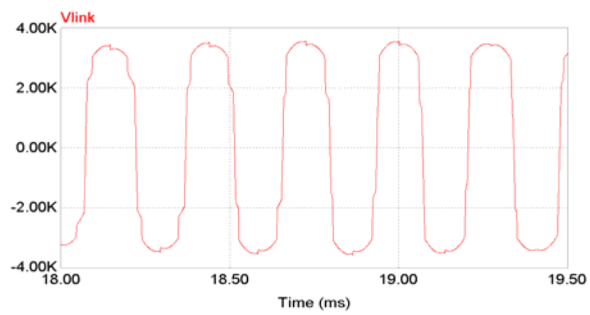

Fig. 5 Link Voltage

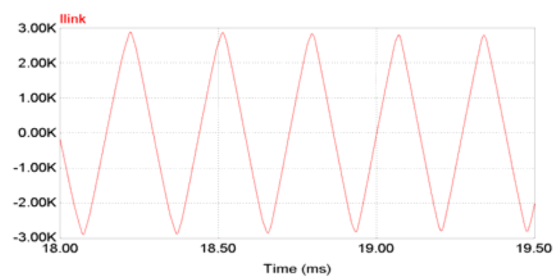

Fig. 6 Link Current

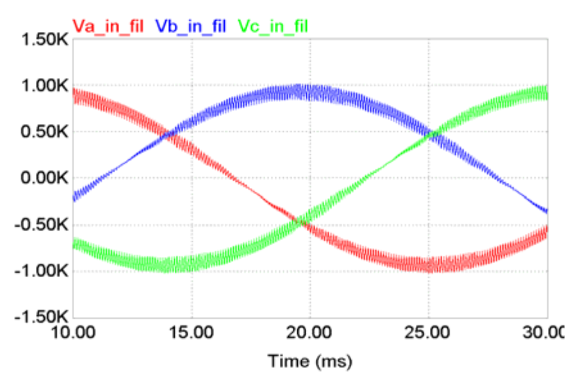

Fig. 7 Filtered Input Voltages for boost case

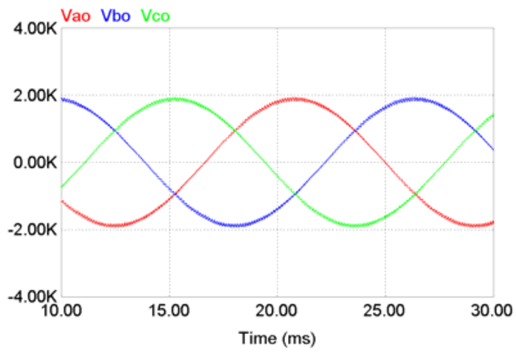

Fig. 8 Filtered Output Voltages for boost case

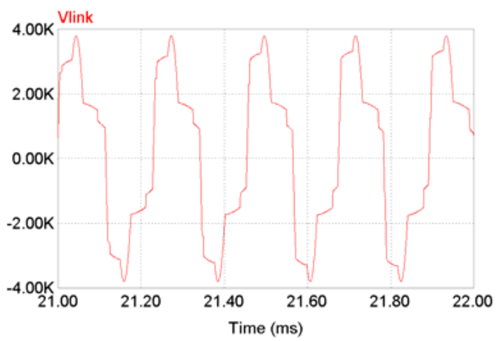

Fig. 9 Link Voltage for boost case

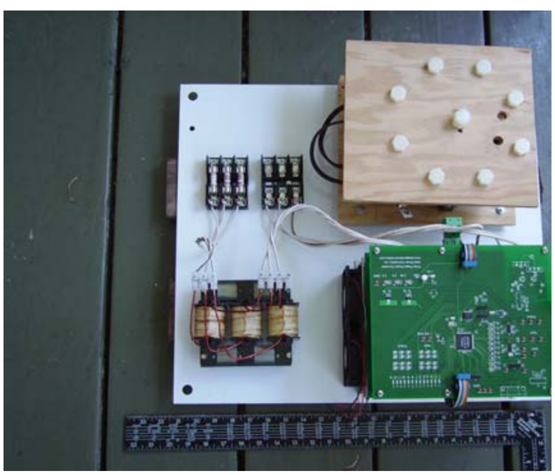

Fig. 10 25kW, 575 VAC prototype in development

V. Conclusion

The Soft Switched AC-Link Buck-Boost Converter will be well suited for wind power converters. Its ability to convert in a single power stage the variable voltage and frequency output from a grounded neutral permanent magnet synchronous wind generator to the constant voltage and frequency of the utility, without a transformer and with high power quality in a compact and light weight converter, while supplying commanded power factor and support for utility faults, is unmatched by other topologies.

Table. 1 Simulation Parameters

Power	2,000 kW
Nominal Link Frequency	3.5 kHz
Power Cycle Frequency	7 kHz
Peak Link Current	2800 A
Link Inductance	73 uH
Link Capacitance	5.75 uH
Switch du/dt at turn-off	240 V/uS
Peak switch blocking voltage	4,000 V (2 X peak line-neutral)
Line inductance input and output	200 uH (4% reactance)
Line capacitance input and output	200 uF

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