INITIAL EXPERIMENTAL RESULTS OF A NEW DIRECT CONVERTER FOR HIGH ENERGY PHYSICS APPLICATIONS

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Abstract

This paper presents practical results for a new type of power supply for high energy physics CW applications. The converter is a direct topology operating with a high frequency (resonant) link. Losses are minimised by switching at zero current. High operating frequency reduces the filter and transformer size. The transformer uses the latest nano-crystalline materials to further reduce losses. Where possible, circuit elements are incorporated into the transformer to reduce the physical size of the converter. Design of this transformer to accommodate the insulation, VA rating and circuit elements is non-trivial. The Radio Frequency power generated is stable and predictable, whilst the reduced energy storage in filter components removes the need for crowbar circuits. Potential benefits of this converter when compared to conventional approaches are discussed. These include reduced energy storage, reduced turn-on time and enhanced energy density when compared with existing topologies. Preliminary practical results are promising and are presented along with simulation results.

INTRODUCTION

High energy physics experiments require high quality, predictable and stable power supplies to generate the required power for the klystrons and IOTs. Conventional approaches are based upon line frequency designs where the size and cost of the converter was less important in the design process compared to today's research environment.

The converter presented in this paper aims to meet these requirements, whilst at the same time offering reduced energy storage, and the potential to produce a highly compact, high energy density converter.

The converter uses the latest nano-crystalline materials in the magnetic components to allow for reduced loss and high operating frequency, in turn reducing the size of the output filter required to meet the output voltage specification such as that given in[1]

OVERVIEW

Referring to Figure 1, the converter consists of 6 bidirectional switches each formed from two IBGTs and associated diodes. In this case, there are nine possible switching states that may be applied. These states consist of three zero states, where the energy in the tank is allowed to circulate, and six states that each apply one of the three line voltages or its inverse, as shown in Table 1. For the application being considered, ripple in the DC voltage must be below 1% [1]. To achieve this, several control schemes have been considered. Initially such control strategies focused on maintaining the input power, such as those described in [2] and [3]. However, such approaches were unable to maintain operation of the tank with low Q (required to minimise stresses on the components and energy storage in the circuit). Instead the controller selected applies a state to the tank such that the resonant tank envelope will operate with as little deviation as possible. This is achieved by predicting the possible resonant tank voltages that will result from each possible switching states. The controller then selects the state which will result in a resonant capacitor voltage closest to the reference at the next half cycle. Consequently, this will produce the best possible resonant tank voltage regardless of input perturbations and harmonics. [4]

Table 1: The 9 possible switching states and corresponding IGBT gatings.

State	S1	S2	S3	S4	S5	S6	Voltage Applied
1	1	0	0	1	0	0	Vab
2	0	1	1	0	0	0	Vba
3	1	0	0	0	1	0	Vac
4	0	1	0	0	0	1	Vca
5	0	0	1	0	0	1	Vbc
6	0	0	0	1	1	0	Vcb
7	1	1	0	0	0	0	0
8	0	0	1	1	0	0	0
9	0	0	0	0	1	1	0

TRANSFORMER DESIGN

Integral to the converter topology is the high voltage (step up), high frequency (20kHz) transformer. In its ideal form the converter output stage consists of a resonant inductor, capacitor and an ideal transformer feeding a single phase filtered rectifier, as shown in figure 1.

In reality, such an ideal transformer is impossible, and contains parasitic components such as leakage inductance and interwinding capacitance. Consequently, the effects that these components may have on the resonant operation of the converter needs to be considered. It would be beneficial if these leakage components are integrated into the resonant circuit components, and ideal if all of the resonant components where contained within the transformer.

Due to the high frequency of operation, materials such as nickel laminations are unsuitable for the transformer de-

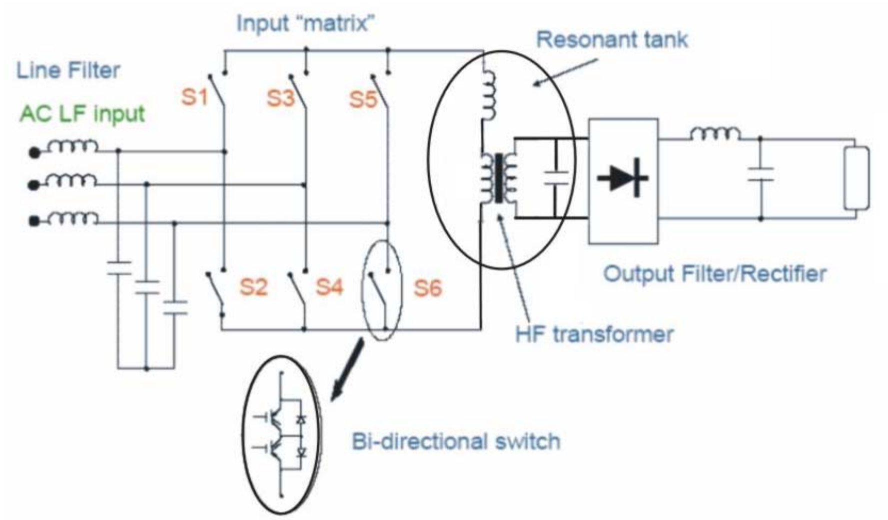

Figure 1: The circuit topology.

sign, unless operating at a relatively low flux. For this design a nanocrystalline core (VAC W758) was used, offering much lower losses at high frequencies when compared to more conventional materials. Consequently, the transformer is able to operate at a much higher flux level, and be physically much smaller than would otherwise be expected. In this case, a core loss of approximately 70W/kg is anticipated when operating at 0.9T. The final transformer is shown in Figure 2

Comparison of analytical estimations with those practical results obtained from prototype transformers proved to be accurate, with only a very small error existing between the simulated inductance and capacitance and those found by experimentation. This has lead to a preliminary design incorporating approximately 15% of the required resonant inductance. A second tuning inductance provides the remaining resonant inductance.

Figure 2: The Final Transformer.

RESULTS

To demonstrate the feasibility of this approach an experimental 25kW converter has been constructed. The converter is designed to produce 25kV at 1Amp for applications such as those outlined in[1]. Preliminary results obtained from the prototype can be observed in Figure 3. In this case, the converter is producing approximately 15kW, at 20kV DC. It can be seen that resonant tank operation is controlled. To reduce low frequency perturbations the controller is designed to produce a high frequency ripple on the resonant tank envelope, as observed in the figure. This high frequency perturbation can be readily removed by filtering. At present, errors caused by the use of a variable supply are causing a poor input current waveform. Once the converter is commissioned for 25kV operation these waveforms should improve significantly. When complete the converter should be able to track demand changes from 10-100% and operate under zero output load conditions. The control scheme has also been tested for operation with a 10% variation in resonant components and has been shown to meet target specification under such conditions.[5]

CONCLUSION

The novel technique presented here has the potential to offer significant size and weight advantages compared to existing topologies in the area of direct power conversion for high power, RF applications. Careful design of the resonant transformer is vital if the leakage inductance is to be anticipated. Successful operation of the prototype converter shows that resonance is achieved using the leakage components of the transformer, and that this resonant operation may be controlled by the scheme outlined. The converter outlined may be scaled up to operate at almost any foreseeable power requirement.

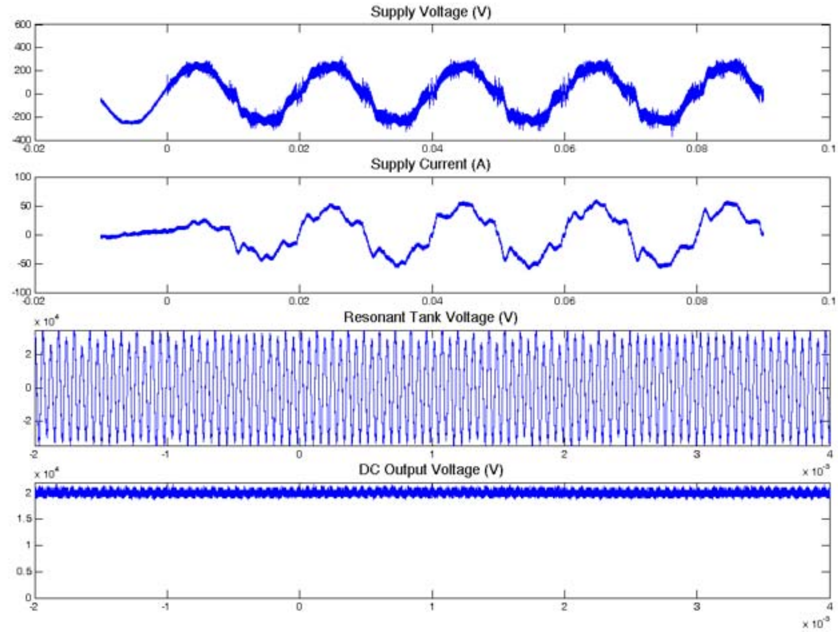

Figure 3: Preliminary Experimental Results.

REFERENCES

[1] C. Christou, A. Moss, "Technical Specification for the Radio Frequency Amplifier for the Diamond Light Source Booster Synchrotron," *Rutherford Appleton Laboratory*, 2003.

[2] P.K. Sood, T.A. Lipo, "Power conversion distribution system using a resonant high frequency AC link," *IEEE Trans. on Ind. Appl.*, pp. 533–541, 1986.

[3] M. Catucci, J.C. Clare, P.W. Wheeler, "Predictive Control Strategies for ZCS Direct Converter HV Power Supply," *EPE Conference CD*, p. 537, 2005.

[4] D. J. Cook, M.Catucci, J. C. Clare, P. W. Wheeler, J. S. Pryzbyla, C Oates, "Development of a 25kV 1 Amp Direct Conversion Power Supply for High Power RF Applications," *EPE Conference CD*, p. 519, 2005.

[5] D. J. Cook, M.Catucci, J. C. Clare, P. W. Wheeler, J. S. Przybyla, "Design Of A Direct Converter For High Power, Rf Applications," *PAC Conference CD*, 2005.