

A CROWBARLESS HIGH VOLTAGE POWER CONVERTER FOR RF KLYSTRONS

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Abstract

Advances in power electronic components make feasible the production of switch-mode power converters in module sizes exceeding 100kW. The development of a power converter system in modular form for feeding high power CW RF klystrons will be described. It has the advantage that the stored energy at high voltage is so small that the conventional crowbar protection is unnecessary. Results of work to test the principle on a 50kW klystron used for power testing accelerating cavities at Daresbury will be presented.

1 INTRODUCTION

Power Converters for high power RF systems have recently been under review at Daresbury for two reasons. The drive for higher reliability on the SRS has been focused on those areas which caused the highest loss of beamtime. After the investments on new power converters for the storage ring magnets [1] and uninterruptible power supplies for the general 415V distribution [2], the RF power source is the next area to receive attention. Also, the DIAMOND project will require a more modern power converter than the SRS, and a design which can be tailored in size to suit different RF power tubes seemed very desirable.

Advances in power electronic components now make possible the production of switch-mode power converters in module sizes exceeding 100kW. The use of high frequency inverters means that the stored energy at the high voltage end is greatly reduced compared with a line-commutated rectifier. The design described here seeks to further minimise the stored energy by using several inverters to achieve the total power, with controllable phase delays to force the ripple frequency so high that filters storing only a few joules will suffice to produce an acceptably smooth DC. This means that it will be possible to eliminate from the power system fast protection by electronic crowbar. This is an expensive device which is difficult to make operate reliably without triggering on noise and so causing unnecessary losses of stored beam.

A replacement power converter for the SRS would be rated at 48kV 12A, the current being reduced compared with the original, which was 15A, because of the improved efficiency of modern klystrons.

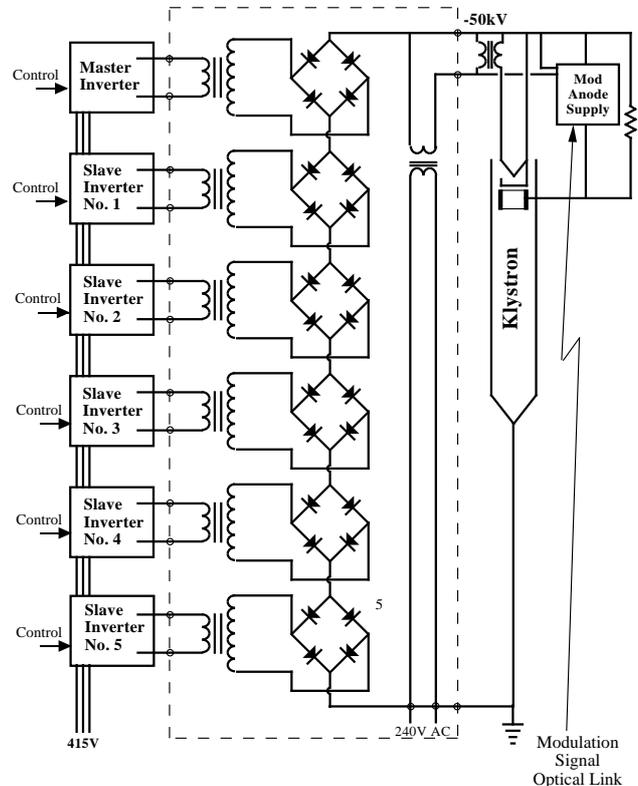


Figure 1: Concept of a Six Stage Power Converter

This paper describes a pilot study to test a novel way of controlling the inverters, and was designed to deliver low voltage at high current in order to use a water cooled resistor as a load. At a later stage it is planned to build a second output unit to power a television transmitter klystron. This forms part of a test rig used for high power tests on SRS accelerating cavities.

2 DESIGN DETAILS

2.1 The Inverter

Some tests had been performed at Daresbury to evaluate a power converter for possible use on the smaller storage ring magnet circuits. It utilised a 25kW half bridge inverter of the resonant type, in which a series resonant circuit is operated at a frequency higher than its natural resonant frequency. This is known as the "Foch" type [3], and is only one of a number of variants of the switch-mode inverter. It uses two IGBTs operating at between 20 and 40kHz. It was realised that this would be a good "building block" for the pilot high voltage power converter.

Its operation may be understood considering a series resonant circuit LC with a load resistor R connected across the capacitor (known as a “Boucherot” circuit [4]). When driven by a sinusoidal voltage V_s at the resonant frequency, it has the property that the current in the load is given by:-

$$V_s / j2\pi fL$$

where V_s is the supply voltage
 f is the frequency
 L is the inductance

The current is independent of the load value, making the circuit a natural current source. A practical inverter is driven instead by two switches in a half bridge or four switches in a full bridge, as shown in Figure 2.

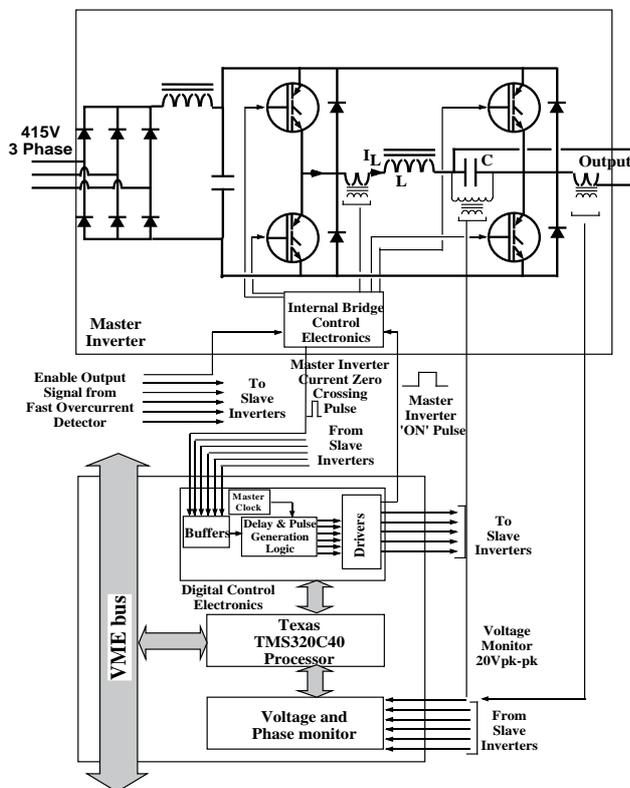


Figure 2: Full Bridge Inverter and Control Electronics

By making switch-on occur as the current in the inductor crosses through zero, and switch-off occur at a variable time before the next current zero, it is possible to control the power delivered to the load. In the conventional application, control is achieved by use of a timer, which controls the “on” period of the switches under control of two analogue feedback loops, an inner current loop and an outer voltage loop. The frequency and phase of the oscillation are normally of no concern to the user, because the inverter output is rectified and smoothed. Since switching occurs at or near current zero, commutation is softer than with chopper types, and

therefore the electromagnetic noise generated is much less for equivalent output powers.

2.2 Digital Control Electronics

It is a feature of this type of inverter that the operating frequency varies as the output voltage and current change. Thus in order to use a bank of inverters in a multi-phase arrangement so as to minimise output voltage ripple, the phase relationship must be preserved despite frequency changes. The present design achieves this by monitoring the operation of one of the inverters, referred to as the master, and controlling the operation of the others, referred to as the slaves, in synchronism with the master, such that the required phase relationship is maintained.

It was decided to achieve the required control using a fully digital system, which generated the pulses to switch the IGBTs in all the inverters directly. This would give full control of the bank of inverters via feedback loops implemented in a digital signal processing system. A six channel delayed pulse generator was designed into a large field programmable gate array, Altera type EPM9480RC208/15. On receipt of a trigger, which is a pulse generated by the master inverter when the inductor current crosses through zero, it delivers up to six pulses, individually controllable in delay and duration.

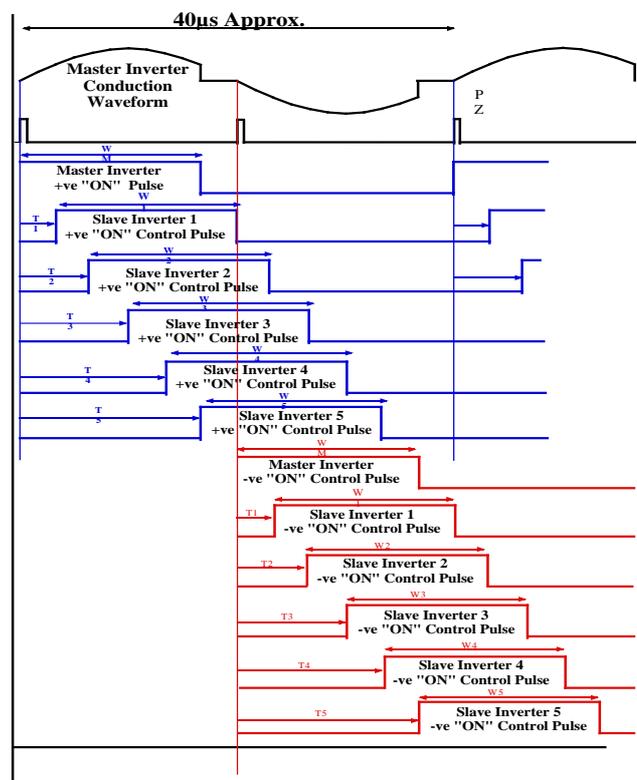


Figure 3: Output Pulse Train

A second gate array contained logic to measure the period of oscillation of the master and the delays to the zero crossing points of all the slaves. It also received the

outputs from a bank of ADC's and organised the data for fast readout to a digital signal processor. The Texas TMS320C40 was chosen for the prototype work because it can handle many control loops at the sampling rate required, and has six fast communication ports making possible a straightforward interface to the pulse generation logic. Figure 2 also shows a block diagram of the electronics

2.3 Output Transformer and Rectifier

For the initial tests it was decided to build a unit to combine the outputs of two inverters in several configurations. Two transformers each had four secondary windings with a rectifier bridge for each. With all windings connected in series it delivered 75 amps at 640 volts, suitable for connecting via a small load resistor back onto the 580 volt rectified mains, thus enabling tests up to full output to be performed whilst only dissipating 4.5 kW. With the bridges connected in series in pairs, one from each transformer, and the four pairs paralleled, it delivered 300 amps at 160 volts, suitable for use with an existing water cooled dummy load.

3 EXPERIMENTAL RESULTS

Early tests were carried out using a simplified version of the delayed pulse generator, which measured the period of oscillation and delivered two output pulses of the same duration with one delayed by 90 degrees. This revealed that time delays within the local control electronics of the inverters needed to be reduced to achieve reliable control over the full output range. It was possible to assess the effects of the two inverters having slightly different resonant frequencies, so that tolerances can be specified for the final version. Because comprehensive monitoring is available via the digital electronics, the final system will be able to calculate the values of tuning components required to balance the outputs.

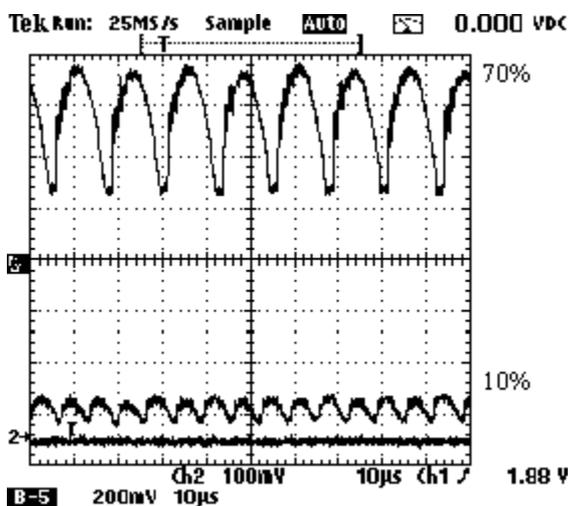


Fig 4. Waveforms at Two Output Voltages

Figure 4 shows oscillograms of the unsmoothed DC at 10% of rated output voltage, the ripple frequency being 160kHz, and also at 70% of rated output voltage, the ripple frequency being 80kHz. When the full electronics became available, digital feedback loops were applied and it was demonstrated that sufficient bandwidth was available to reduce 300Hz ripple fed through from the mains rectifier. The results show that a full power converter for a synchrotron light source RF system can be specified with confidence.

For these tests, the delay in switching the second inverter was computed simply by dividing the measured period by six, and operating the slave from the fourth channel. It is apparent that good ripple cancellation will be obtained for at least 12 pulse rectification.

4 FUTURE PLANS

The next stage of the work will be to build a high voltage output unit to work with the existing two inverter system, and perform tests using the TV transmitter klystron in the Daresbury high power cavity test rig.

After that, specifications will be prepared for components which can be used in a modular approach to building high voltage crowbarless power converters of different power ratings. Of particular interest are a converter at 36kV and 4 amps for a 60kW tube and one at 48kV and 8 amps for a 150kW tube, these two being the most likely choices for the five New European Light Source projects. A power converter at 48kV and 12 amps would be required for the SRS if it needed to be capable of powering any of the 250 kW klystrons currently available.

5 ACKNOWLEDGEMENT

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6 REFERENCES

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