A MILL MOTOR INCHING DRIVE USING A THREE PULSE CYCLOCONVERTER WITH DOUBLE INTEGRAL PHASE CONTROL.

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ABSTRACT

This report describes the first commercial installation of a three pulse cycloconverter drive using a new type of phase control modulation method developed by the authors called double integral control. The new control method gives the three pulse cycloconverter similar performance in both harmonic output and speed range to a six pulse cycloconverter, but at a much reduced cost and much higher efficiency. The particular application is an inching drive for the maintenance of various mills at a large copper mine in Canada. There are 5 mills at the site, each of which is driven by one or two synchronous motors rated at 4160V 60Hz 4000 hp (3000kW). The motors are run direct on line but started as wound rotor induction motors using their damper windings, which are brought out via slip rings. The cycloconverter is rated at 0-570V, 0-10Hz, 1500A with a supply input of 600V, 60Hz. A mill to be turned for maintenance is connected to the cycloconverter with its motors configured as synchronous machines with their damper windings shorted. The cycloconverter, with its adjustable low frequency output, is then used to turn the mill as required. Starting torque for the mills can be up to 1.5 times the rated torque which dictates the high current rating of the cycloconverter. The cycloconverter is rated for continuous duty to allow for possible future applications at the site. With an efficiency of greater than 99.5%, only fan cooling is required.

Introduction

At present, practical 3 phase cycloconverter drives use a minimum configuration of three 6-pulse bridges, requiring a minimum of 36 thyristors and a transformer with three isolated three phase windings to isolate the bridges. The minimum theoretical configuration, though, is the 3-pulse circuit as shown in Fig. 1. This circuit uses only 18 thyristors, does not require a transformer, and is much more efficient than the 6-pulse configuration. Also, most of the 3-pulse related harmonics that appear on the output are in phase and so do not appear on the motor windings. At low output frequency and voltages, the motor voltages and currents are identical to those of a six-pulse cycloconverter. Traditionally, it has been stated [1] that the 3-pulse cycloconverter is not practical due to the low frequency intermodulation products which can be generated on the output. These subharmonics are completely suppressed by the use of the double integral phase control method developed by the author [2]. This phase control method also solves other problems such as control with discontinuous current and bank cross-over determination.

This report is a brief description of the first commercial installation of a 3-pulse cycloconverter using the new modulation technique. The application is an inching drive for the maintenance of various mills at a large copper mine in Canada. There are 5 mills at the site, each of which is driven by one or two synchronous motors rated at 4160V 60Hz 4000 hp

(3000kW). A mill to be turned for maintenance is connected to the cycloconverter with its motors configured as synchronous machines with their damper windings shorted. The cycloconverter is supplied from a 4160 to 600V transformer and is capable of producing an output voltage of up to 570V. This is enough voltage to operate the motors up to a frequency of 9Hz, so this was chosen as the maximum design frequency, although the cycloconverter itself is capable of operation at up to half the mains frequency [2]. The mills require up to 1.5 times rated torque, so the cycloconverter was designed to supply up to 1500A current. Although only intermittent duty is required for inching purposes, the drive was designed for continuous operation to allow for possible future needs. With an efficiency at full voltage and current of about 99.6%, the cycloconverter is compact and requires only fan cooling. The front and rear views of the cycloconverter cabinet, which is 2.3 m tall, are shown in Fig. 1.

Figure 1. Front and rear views of the cycloconverter cabinet.

Power Circuit

The power circuit of the 3-pulse cycloconverter is shown in Fig. 2. The circuit is conventional. The thyristors are arranged into three modules, one for each output phase, each complete with heat sinks and cooling fans. The modules were supplied ready built and tested by the thyristor manufacturers. They are standard modules which are also used in soft starters and have proven reliability.

Control Method

The control method used is double integral control. In this method, the output waveform for each output phase is divided into intervals called trigger periods as shown in Fig. 3, each of which contains one thyristor firing. With the exception of the trigger period immediately after a bank cross-over, the trigger period starts and finishes when the expected output waveform
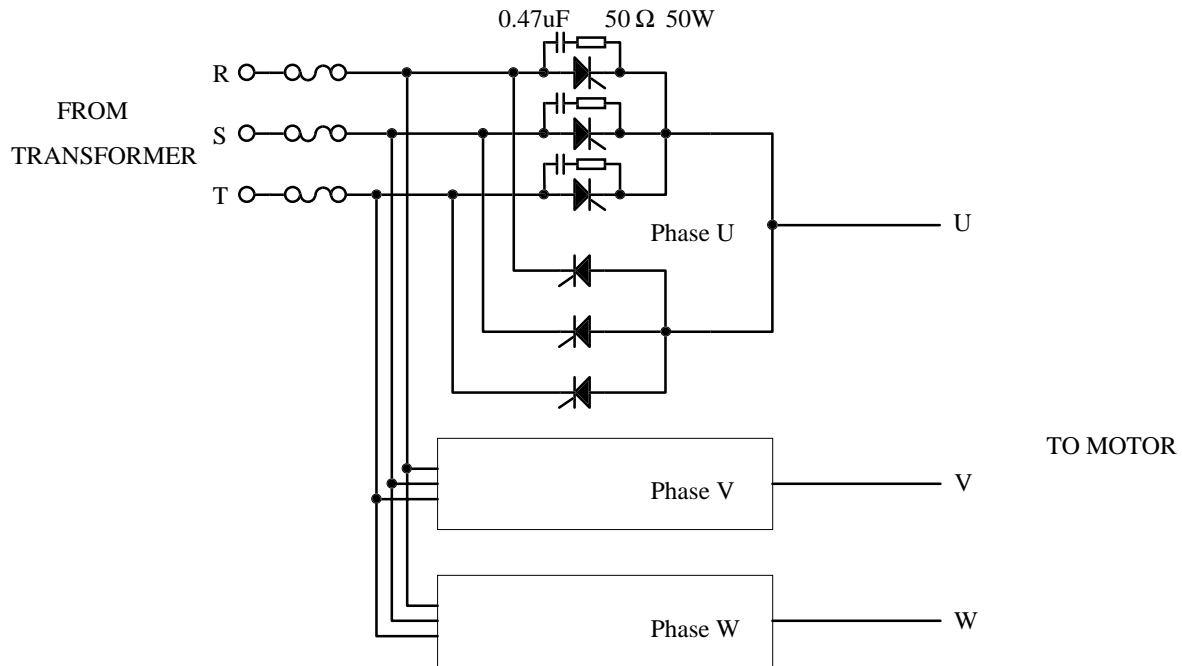
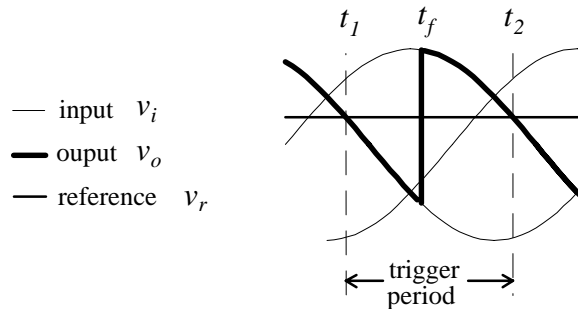Figure 2. Power circuit of the 3-pulse cycloconverter

Figure 3 Trigger periods used for double integral control.

crosses the reference waveform. The trigger period after a bank cross-over starts at the time of bank cross-over to ensure full output waveform control at all times.

In double integral control, the thyristor trigger instant, t_f, is chosen to satisfy the equation:

$$0 = \int_{t_1}^{t_2} \int^{t} (v_o - v_r) dt^2 + K(t_2 - t_1) \int_{t_1}^{t_2} (v_o - v_r) dt \qquad (1)$$

where t_1 and t_2 are the start and end of a trigger period and v_o and v_r are the output and reference voltages as shown in Fig. 3. K is a stability constant, usually set to 0.5. Ignoring the right hand single integral term, which is a stabilising term normally evaluating to zero, satisfying the equation keeps the average of the integral of $(v_o - v_r)$ zero. By keeping the
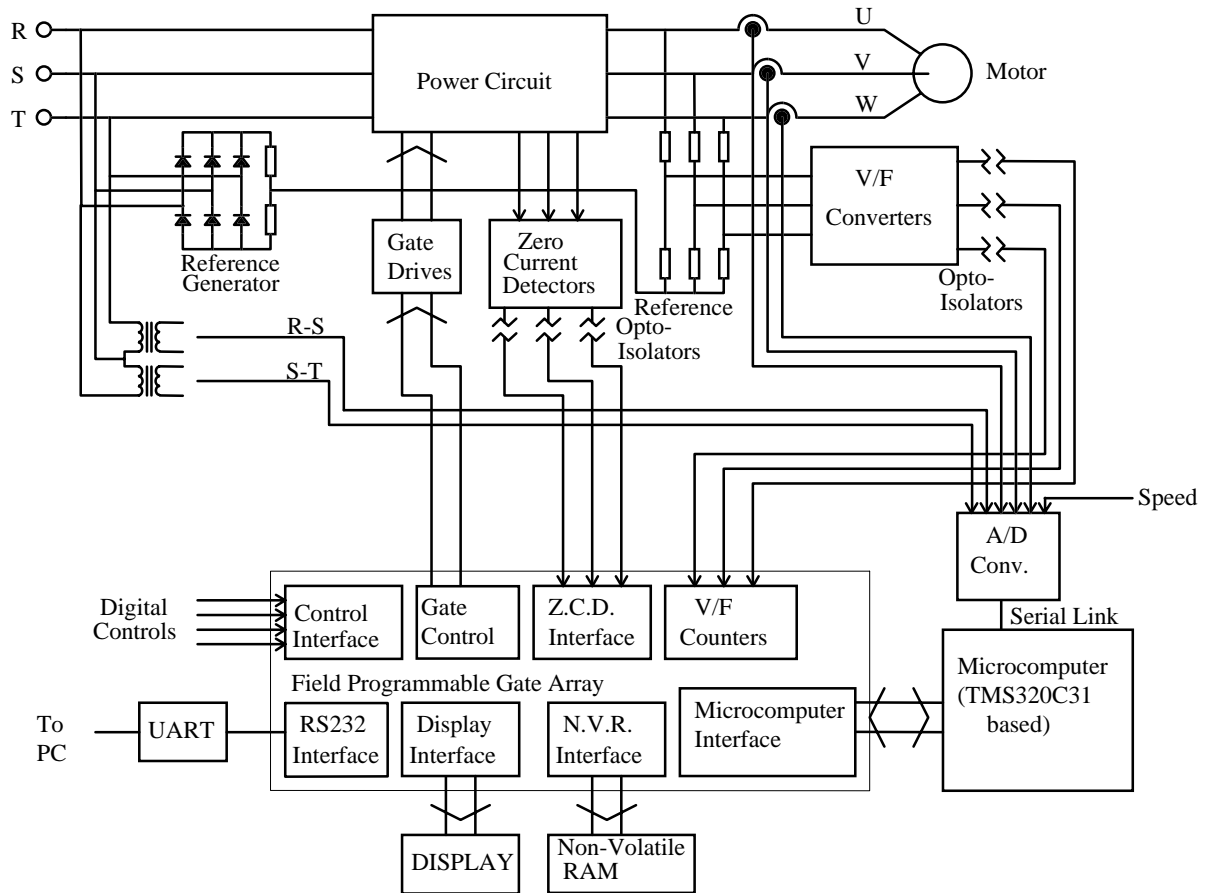
Figure 4. Block diagram of the control circuit.

average of this integral zero, the average of the motor flux error, and the average ripple current, are kept at zero. The control method is implemented in practise by evaluating the right hand side of equation (1) repeatedly from the start of the trigger period at a rate of 120 times per mains input cycle and triggering the thyristor when the equation is satisfied. Using this method, rather than estimating the trigger time in advance, ensures correct triggering even when the output voltage becomes indeterminate due to discontinuous current.

A major problem for the cycloconverter without circulating current is the determination of the time to cross between thryistor banks in each phase. As can be seen from the high frequency equivalent circuit of one phase of the motor shown in Fig. 5, the ripple current can be approximated by:

$$\text{ripple current} \propto \int (v_o - v_r)dt - \frac{1}{3} \sum_{U,V,W} \int (v_o - v_r)dt \tag{2}$$

Since with double integral control, the integrals in equation (2) are known and controlled, the polarity of the ripple current in each phased is always known. The bank cross-over time is chosen to be the first time when the actual current is zero (and thus all thyristors in that phase

are off) and the polarity of the integral of $v_o - v_r$, is positive for the positive bank, or negative for the negative bank. This corresponds to the first time the current is zero after the fundamental component of the current has passed through zero, which is probably the optimum bank cross-over time.
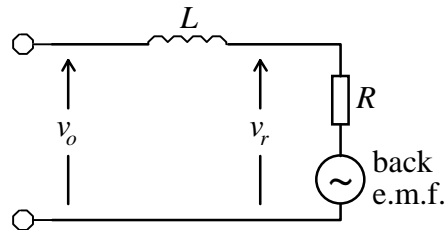

Figure 5 Per phase high frequency equivalent circuit of a motor with values of the cycloconverter output and reference voltages shown.

Control Circuit

The control circuit of the cycloconverter is shown in Fig. 4. The control functions are implemented using a Texas TMS320C31 DSP, with an ACTEL A1225XL field programmable gate array used for all digital interface logic and a 12 bit A/D converter used to read in all analogue inputs.

The double integral control method requires precise feedback of the integrals of the output phase voltages. These integrals are obtained here by counting the output pulses from three precision voltage to frequency converters. The output phase currents are also measured, but are used only for protection as they are not used in the double integral control method.

Waveforms

The cycloconverter was tested with both induction motor loads and passive loads. An example of the waveforms obtained is shown in Fig. 6. The load for this test is a passive RL load simulating two mill motors at full load for 9 Hz frequency scaled for 100:1 of the output current and for 415V, 50Hz input rather than the final 600V, 60Hz input to suit the supply available at the test laboratory. The input transformer was also simulated with a suitable line input inductance. This inclusion is the reason for the pronounced commutation glitches which can be seen on the output voltage waveform.

Note that the crossing between thyristor banks is particularly rapid and does not contribute any current distortion.
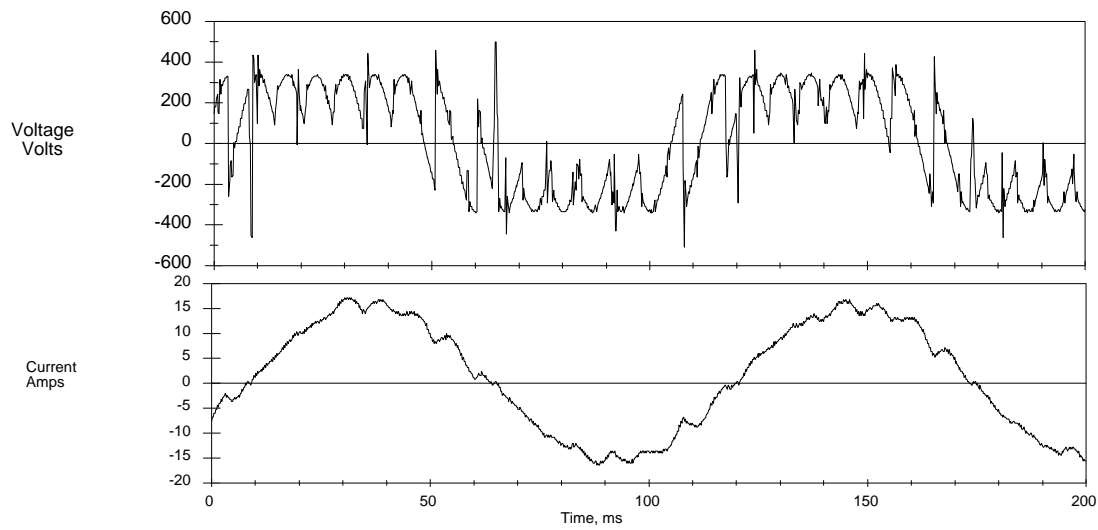
Figure 6. Output phase voltage with respect to input neutral and output phase current for a passive load simulating two mill motors at full load.

Conclusion

The first commercial installation of a 3-pulse cycloconverter drive using double integral control achieved its objectives and is an economical replacement for the former mechanically switched inching technique.

References

1.   B. R. Pelly, "Thyristor phase-controlled converters and cycloconverters", Wiley-Interscience, 1971.

2.   G. P. Hunter, "New improved modulation method for a cycloconverter driving an induction motor", IEE Proc., Pt. B, vol. 135, No. 6, pp. 324-333, November 1988.