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CHARACTERISTICS OF INVERSION OPERATION ON FERMILAB PHASE CONTROLLED PULSED POWER SUPPLIES

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SUMMARY

A well known property of phase controlled rectifiers with pulsed inductive loads is the ability to advance firing angles from full rectification (positive voltage) to full inversion (negative voltage). Though these properties have been effectively used in the Main Ring power supplies, they have not been extensively utilized for beam line magnet power supplies. Modifications to permit advancing phase angle sufficiently to permit inversion were made on TransRex 500 KW power supplies and Ling 55 KW power supplies. The objective of these modifications was to rapidly reduce the current in magnet loads to zero upon command. The modifications required and the performance of the power supplies are discussed.

GENERAL

The TransRex 500 KW and Ling 55 KW power supplies are conceptually identical. The power transformer is fed from 480 VAC 3Ø. Direct Current (DC) is obtained by phase controlled thyristors on the secondary side of the power transformer. A free wheeling diode assembly is installed across the output terminals. Voltage or current regulation is selectable.

Virtually all of these power supplies are pulsed; both to reduce power and to reduce heat load. Typical operation requires phasing the power supply on to establish the desired current, flat-topping during the spill time; and then, phasing off the power supply allowing the inductive load energy to be dissipated in the resistance of the load, leads, and free-wheeling diodes. In that these resistances are small, considerable time (seconds) was required to reduce the current to zero.

In reviewing various schemes to minimize this turn off time, inversion of the power supply output voltage seemed an easily achieved possibility. This requires phasing the power supply forward beyond 90^0, reversing the output voltage polarity, and transferring the energy stored in the load back into the AC power line.

INVERSION

Since the power supply output voltage is to be reversed during inversion, the free-wheeling diodes were removed. Additional tests showed, however, that several effects occur to limit the available inversion voltage and diminish the ability to control inversion with simple schemes.

The inductances in the AC circuit of a power supply insure commutation overlap, i.e., more than two thyristors on at one time. This leads to the onset of inversion at thyristor firing phase angles of less than 90^0. If overlap is large, peak inversion voltage is unavailable at a phase angle of 180^0; also commutation failures are more likely to occur. With thyristors, overlap is small, and full inversion voltage is almost possible. For example, since the peak inversion voltage is equal to the peak rectification voltage (with no power transformer tap changing), the 500 KW TransRex (tapped for 100V-5000A operation) can achieve nominally 100V during the inversion cycle. Figure 1 shows the voltage waveform for 4500A peak current. The Ling 55 KW power supply voltage waveform is shown in Figure 2. Here, nominally 270V of inversion are maintained through the inversion cycle. Figure 3 shows a comparison between Ling with free-wheeling diodes installed and then with inversion operation. The load is the same in both cases. It can be seen, and as expected, that the major effect of inversion is to eliminate the long tail.

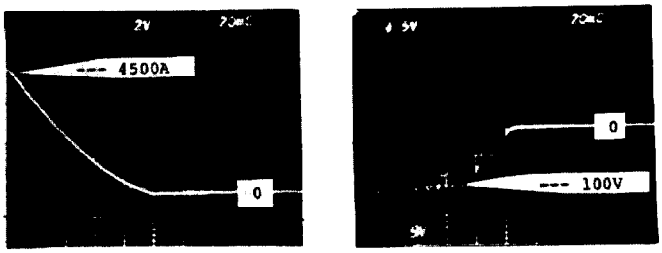

Figure 1

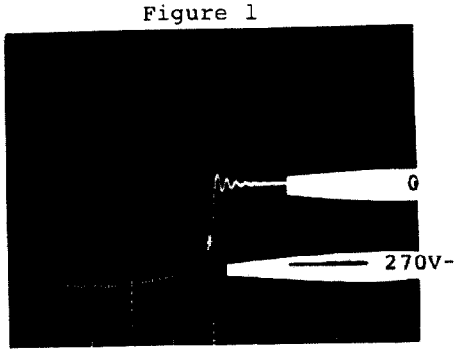

Figure 2

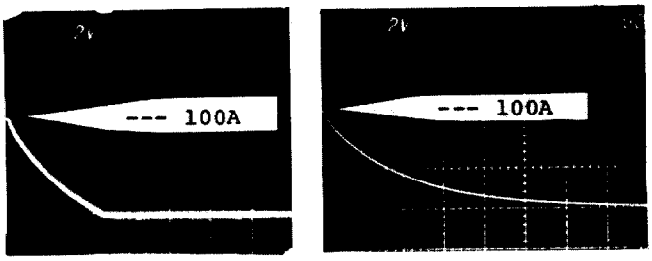

Figure 3

Inversion
500 ms/cm

Without Inversion
500 ms/cm

Commutation failures do occur if the firing phase angle is advanced too far, and the regulator electronics must be constructed to minimize this potentially damaging condition. The DC circuit attached to the power supply output terminals and the power supply reactances can form a lightly damped oscillatory system with a natural frequency in the range of power line frequencies. This has, in fact, occurred in the 500 KW power supplies. This effect leads to large alternating voltages being impressed across the load. The oscillations are maintained for some seconds until the energy stored in the load is reduced adequately. This condition is somewhat startling with considerable audible noise being generated.

It should be noted that the free-wheeling diodes are removed to permit the power supply output voltage to go negative. They do, however, play an important part in ripple reduction for the loads typically found at Fermilab. With inversion operation, ripple voltages are quite high and, in fact, at zero current, the power supply output terminals alternate equally between plus and minus one-half peak voltage. This can be remedied, however, by using the bypass thyristor actively, i.e., use it as a diode during rectification.

Circuit Modifications

Both power supplies have (fortunately) nominally 180^0 of firing angle control possible. Though complex schemes are possible, it appeared that only minor modifications would be required to affect adequate inversion. The free-wheeling diodes were removed and replaced with a single bypass thyristor with trigger control.

This circuit is necessary to protect the magnet and power supply in the eventuality of an emergency shutdown or power outage if fuses are open. This thyristor was only used for protection and was not used for ripple reduction.

Modifications to the power supply regulator cards were minimal requiring the addition of a few components to insure adequate phase angle adjustment for good inversion control and a clamp circuit to limit the depth of inversion and prevent resonance.

CONCLUSIONS

Reasonable inversion is possible for the power supplies tested for rather modest changes to the power supplies. The modified regulators will permit diode operation with virtually no circuit changes. As can be noted, in Figure 2 for the Ling, the depth of inversion is not as great as for the TransRex 500 KW. If improved inversion is necessary, more extensive modifications to the firing circuit control will be necessary.

Though each of the loads tested were single power supplies, inversion of series connected power supplies should be a straight forward extension of these modifications.

ACKNOWLEDGEMENTS

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REFERENCES

1. Edward Wilson Kimbark, Direct Current Transmission, Volume 1, John Wiley & Sons, Inc., 1971.