Inverter Development At Utsi

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INVERTER DEVELOPMENT AT UTSI*

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Abstract

A four unit MHD channel inverter system using line or McMurray commutation has been built and partially tested at UTSI. Testing has included using either a D.C. power supply or power from the MHD channel. It was found that a multiple inverter loading units system increases the performance of the UTSI channel by as much as 7 percent for an eight unit loading system. It was also found that substantial electrical filtering of the MHD power must be used to eliminate noise on the MHD power. The noise on the MHD power was found to increase the probability of commutation failure. McMurray commutation was found more susceptible to noise induced commutation failure than line commutation.

I. Introduction

The MHD generator produces direct (D.C.) electric power which must be converted to the more usuable 60 cycle alternating current (A.C.). To accomplish this an inverter is used. For most applications this is most efficiently accomplished by converting the D.C. power to 3 phase A.C. power.

An efficient inverter system for an MHD generator requires not only an efficient inverter but also the proper channel loading scheme. For any diagonal conducting wall power generator, the most efficient means of extracting power from the channel would be to load each electrode pair with an optimum load for that electrode pair. The least efficient way would be to load the channel with one inverter. Optimum loading and maximum power transfer from the channel is obtained when the external load impedance matches the internal load impedance. For optimum loading more than one load is needed since the internal resistance changes along the length of the channel as a result of both the changes in plasma properties and generator cross-sectional area. If the load impedance is not the optimum load for each electrode pair, but instead some channel average, the power output of the channel will be reduced. Of course for a realistic design, it is not economic to have a load or inverter for each electrode pair, but some tradeoff between power generated and load on inverter costs must be reached.

Another problem important to inverter design is the large amount of noise modulation on the D.C. power output of the channel. A typical current output of the UTSI 60° diagonal conducting wall channel into a resistive load is shown in Figure 1.

While the MHD process generates D.C. power, there are fluctuations imposed upon this D.C. power. These inherent fluctuations are a function of the combustion process, near-electrode surface effects and factors related to facilities operations. Since the inversion process will be affected by these variations in voltage and current, it is necessary to minimize them since filtering is expensive. All alternatives to minimize this noise in the MHD channel must also be considered.

The bulk of the energy in these fluctuations resides mainly in the low frequency range (below 200 Hz) and is a result of variations in inlet flow conditions and the nonuniformity of combustion. Under reasonable conditions the intensity of the load voltage and current fluctuations (that is, the ratio of root-mean-squared value to average value) is approximately 5 percent for the UTSI 60° DCW generator. For these conditions the individual interelectrode voltages have an intensity of approximately 15 percent. On the other hand under adverse combustion or flow conditions the interelectrode voltage fluctuations can have intensities ranging from 50 to 100 percent with corresponding variations in load voltage intensity of 30 percent.

As a first step in experimentally investigating inverter loading of the MHD generator and its effect on the channel power noise a 500 μf capacitance was placed in parallel with the resistive load. This resulted in a reduction of the load voltage fluctuations as illustrated in Figure 2. Here the spectral density function for the load voltage shows the rapid roll-off that occurred after the capacitor was switched into the load. No effect on power production was observed when the capacitive filter was used.

From Figures 1 and 2 it can be seen that the noise modulation must be reduced since it will be passed directly onto the inverted 60 cycle power. This would not be acceptable for use in many applications and is above any standard that would be acceptable to the power community.

II. The Loading and Inverter System

The inverter system chosen for the UTSI 60° diagonal conducting wall generator is shown schematically in Figure 3. The system uses 4 equal power 3 phase inverter units rated at 30 KW each. The four unit system will produce approximately 5 percent more power than a single inverter load[1]. The UTSI 60° diagonal conducting wall generator can produce 100 KW for up to 60 minutes in any one test. The four equal power unit inverter system was chosen after considering single, double, four and eight equally channel-spaced or equal power unit inverter systems. Eight equally spaced or equal power inverter units would produce approximately 2 percent more power than the four equal power units but it was decided that the four equal power units would be best for the experiments to be conducted. Optimum loading and power production for the different loading systems was obtained from experiments on the UTSI 60° diagonal conducting wall generator with different resistive loads and the observed voltage and power generated along the length of the channel.[1] The

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four equal power system allows experimentation with phasing control of multiple inverter units and obtaining the additional two percent output at the cost of designing building and experimentally handling the eight units was not deemed worth the effort. The four equal power inverter units of the inverter system operate at different effective load impedances and therefore operate at different current voltage ratios.

Since it is not known which type of inverter system will work best with the MHD channel both line commutated and self commutating McMurray inverter systems† were built.

The basic line commutated circuitry is shown in Figure 4. The system is rated at 1000 volts peak and 210 amps continuous operation. By using different windings on the transformers and different phase angles on the inverter, voltage from as low as 30 volts D.C. to as high as 1000 volts D.C. can be used and fed into the 208 VAC line used as a load. This allows obtaining the optimum load for each of the channel sections being used. The load impedance for each section of the channel can therefore be optimized and easily changed during a test by simply changing the phase angle being used.‡,[2] Each inverter system feeds its power into 3 transformers which can be wired into either delta or wye configuration. The transformers have a series inductance of 375 μh. Using these transformers and two inverter circuits with different delta or wye winding, the output currents can be combined to form a twelve step line current. For McMurray commutation the circuitry of Figure 5 is added to the line commutation circuitry of Figure 4. The McMurray commutation circuitry was designed to commutate currents of up to 200 amps.

III. Experimental Results

The inverter system as built is divided into three sections, a timing cabinet, the thyristor cabinet, and the transformer section. These sections are shown in Figures 6, 7 and 8 respectively[3]. The line commutated inverter circuits were first individually tested using a D.C. power supply as a source and inverter efficiency curves were found. These are shown in Figures 9 and 10. The principle inverter losses are the voltage drops across the conducting thyristor and transformer resistance both which are current dependent. Therefore, at higher operating voltages correspondingly higher efficiencies are expected. It can be seen from Figure 8 that efficiencies of up to 98 percent were obtained with this system. Inverter efficiency plots for the McMurray commutated inverter system have not been obtained at present, but similar losses are expected.

Initial testing of the inverter system with the MHD channel was accomplished by using one inverter unit of Figure 3. The other three sections were not connected and the 2 ohm resistors were used in place of them. From these tests it was found that strong filtering of the MHD channel power was necessary or unacceptable amounts of noise was produced in the A.C. line. Figure 11 shows a typical inverter input D.C. voltage and produced A.C. output current for a phase angle of approximately 160°. It can be seen from these figures that there is a great deal of voltage and current noise on the inverted power and that some voltage filtering is necessary. One interesting result from these tests is that the line commutated inverter will work without a series inductor for MHD application because of the large internal resistance of the channel, the channel therefore appears as nearly a constant current source. This is important since the inductors usually necessary for a line commutated inverter are expensive and can possibly be eliminated for MHD use. Also this leaves the possibility of filtering the noise on the A.C. side of the inverter for a line commutated inverter system.

Figure 12 shows the input D.C. voltage and the A.C. output current of the line commutated inverter when a 9mh series inductor is used on the D.C. side similar to Figure 3. It can be seen from these figures that the inductor reduces the noise on the input voltage but not nearly enough for commercial applications. Continuous stable operation of the inverter using line commutation was obtained in all of these tests.

The McMurray commutated inverter system was tested and conflicting results were found. When used with the D.C. power supply stable conversion for D.C. to A.C. was obtained, but when the McMurray commutated inverter was used with the channel power, stable commutation of thyristors could not be maintained. When commutation failure occurred this resulted in shorting of the MHD channel voltage. It is thought that the commutation failure was caused by the large noise current-voltage fluctuations which suppressed commutation. Heavy filtering of the MHD D.C.

† Commutation is the name given to the action of switching off a thyristor. This is accomplished by momentarily reverse biasing the device, causing the current to go to zero, thereby switching off the thyristor. Line commutation uses the line voltage into which the inverter power is fed to switch the thyristor off. McMurray commutation uses an external circuit which produces an impulse of current through the thyristor momentarily dropping the current to zero, thereby turning it off.

‡ The phase angle alpha is the angle that the generated current is out of phase with the voltage it is being fed into. For inverter operation alpha is between 90 to 180 degrees.

power before the inverter is then necessary for stable operation of the McMurray commutated inverter system. To date the McMurray commutation has been tested with inductive filtering of the MHD channel input voltage (a 9mh inductor in series with the inverter input). With this filtering stable conversion from D.C. to 60 Hz A.C. has not been accomplished. Since then a combination inductive-capacitive filter system has been used with MHD channel and a resistive load and good results on reducing the noise have been observed. It is expected that using strong inductive-capacitive filtering with the McMurray commutation inverter system will result in stable operation, but noise induced commutation failures is more likely for McMurray commutation than when using the line commutated inverter system.

After testing one leg of the inverter system and the associated noise problems, it was decided to first test 2 legs of the inverter system with large voltage-current filtering. This system is the equivalent of Figure 3 with 2 inverters rather than 4 inverter legs being used. The total power of the channel is applied to the two inverter legs. The two legs permit testing with phase control of multiple inverter units with its associated problem. Also the ability to maximize the power output for the two sections of the channel can be tested. Complete testing with this system and the MHD channel has not been completed but when using a D.C. power supply good results have been obtained. The D.C. input voltage of 2 inverter units operating at different phase angles of approximately 130° and 150° using a D.C.power supply. It was found from these tests that 2-line commutated inverter sections can be operated at different input voltages, input currents, phase angles and effective load impedance with no major problem. At present the 2 or 4 inverter unit line or McMurray commutated systems have not been tested with the channel at the time of this writing.

IV. Conclusion

It has been found that multiple inverter units designed to match the internal impedance of a DCW generator channel improve the performance of the DCW channel. The increase is approximately 5 percent for 4 units and 7 percent for 8 units inverter system for the UTSI 60° DCW generator. It was also found that noise modulation of the MHD D.C. power must be filtered substantially or commutation failure is likely to occur. McMurray commutation appears more susceptible to this than line commutation. The noise generated on the MHD output D.C. power was observed passed directly onto the A.C. line. It was also observed that a line commutated inverter would work without a series inductor, leaving the possibility of filtering the MHD channel noise on the A.C. line. It has also been found that multiple line commutated inverter units can be used together with the same A.C. feed line, even though different phasing is used on the inverters.

References

1. Barnett, Larry Roger, The Design of a Thyristor Inverter System for Loading a Diagonal Conducting Wall Magnetohydrodynamic Generator, M.S. Thesis, The University of Tennessee, June, 1975, pp. 21-34.

2. Bedford, B.D., Hoft, R.G., Principles of Inverter Circuits, John Wiley & Sons, Inc., 1964, pp. 5588.

3. Barnett, Larry Roger, op cit pp. 58-91.

Figures

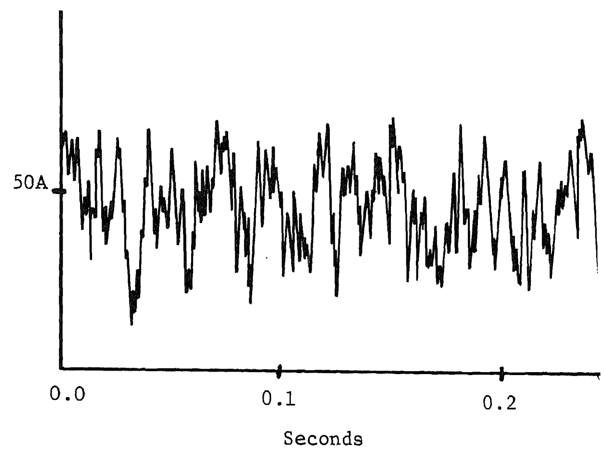


Figure 1. Total current for channel into a resistive load vs. time for Run #1548. Note the large amount of noise modulation on the D.C. power generated.

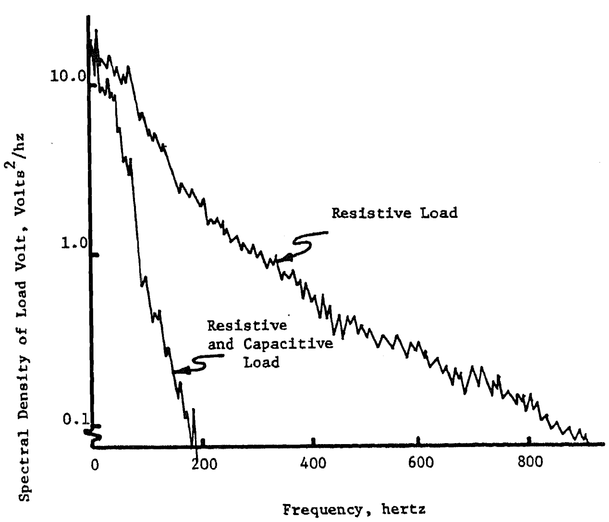


Figure 2. Spectral density of load voltage with and without a capacitor in parallel with the load resistance. Note that without the capacitor there is a large amount of noise on the voltage as high as 1000 Hz.

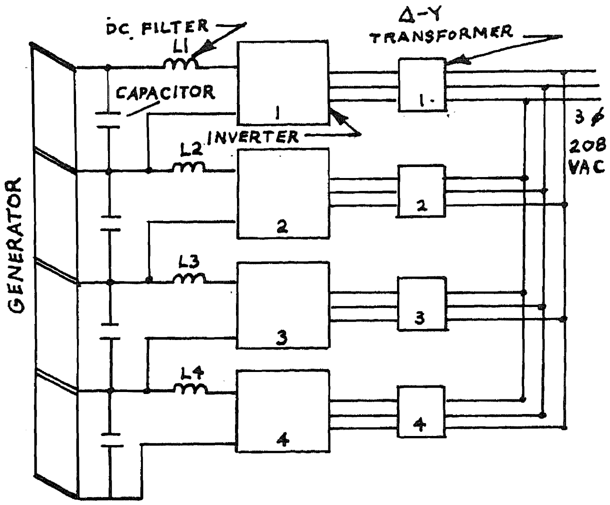


Figure 3. Inverter system chosen for the UTSI 60° diagonal conducting wall generator. The power takeoff from the channel are chosen so that each inverter unit handles an equal amount of power from the channel. The system uses both inductive and capacitive filtering of the channel power. The output power is fed directly into a 208 VAC 3-phase 60 cycle line power grid used by the facility.

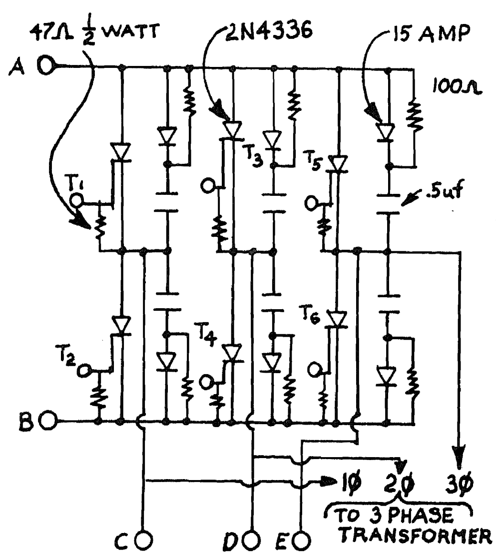


Figure 4. Basic line commutated inverter 3-phase circuit used. This inverter unit employs a dv/dt suppression circuit to minimize the possibility of the thyristor turning itself on from a fast forward voltage pulse.

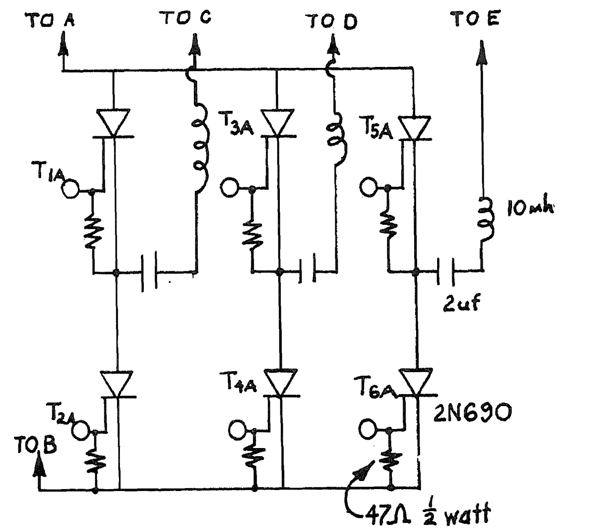


Figure 5. Add on auxiliary circuit for McMurray type commutation. This circuit is added to the basic thyristor line commutated circuit to make it a McMurray self-commutating system.

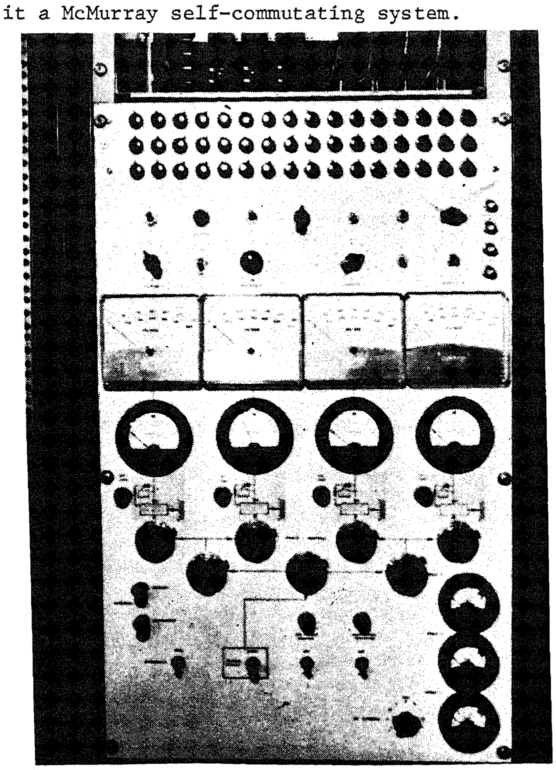


Figure 6. Pulse control and trigger cabinet. This cabinet contains all of the circuitry that generates and controls the 20 volt pulses that turn on each of the thyristors. Each pulse can be individually phase controlled relative to all other pulses. The phase of each inverter unit, 2 inverter units at a time or all 4 inverter units can also be varied simultaneously. The D.C. input voltage and current and A.C. output current is also displayed in this unit.

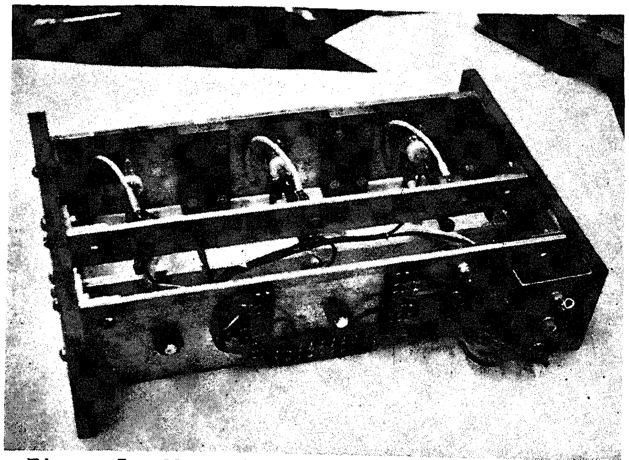


Figure 7. Main thyristor bridge unit for line commutation. Four of these units are used to make up the main switching units for the inverter system.

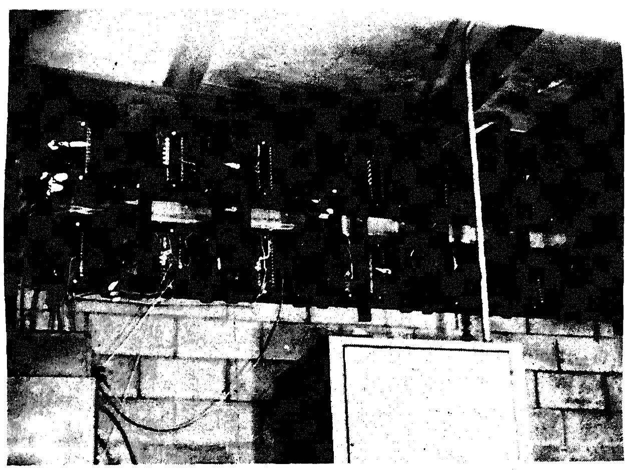


Figure 8. The twelve 10 KVA power transformers. These transformers have silicon steel cores and very little loss for either the 60 cycle power or the high frequency noise. The transformers have duel winds on both the primary and secondary. The primary has taps which give a voltage step capability of from zero to 150 volts in 10 volt steps. The secondary windings have zero, 52, 60, 104 and 120 volts. These transformers can be convected in either Delta or wye configurations.

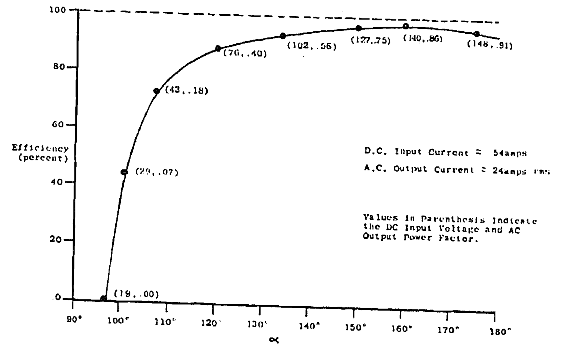


Figure 9. Line commutated inverter unit efficiency vs. firing angle for a constant D.C. input current.

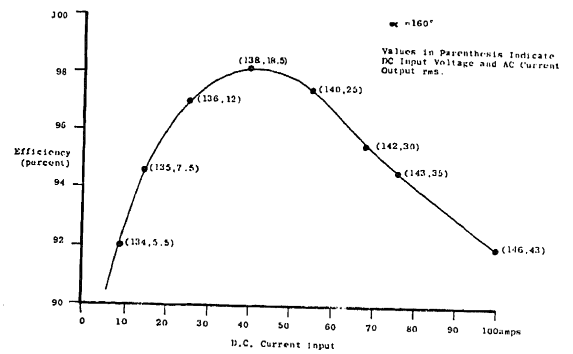
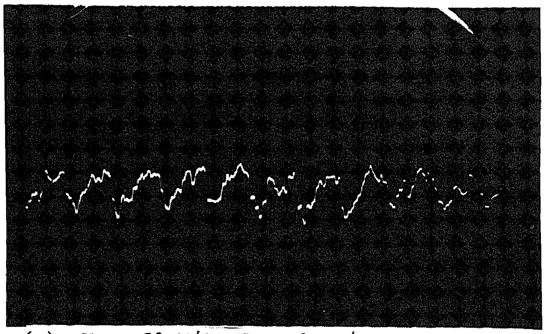
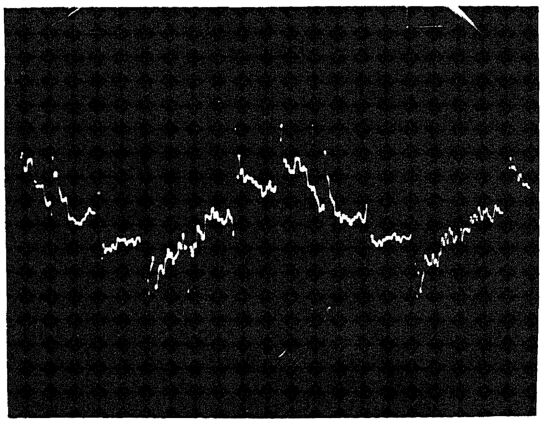


Figure 10. Line commutated inverter unit efficiency vs. D.C. input current for a constant fixing angle of 160°.

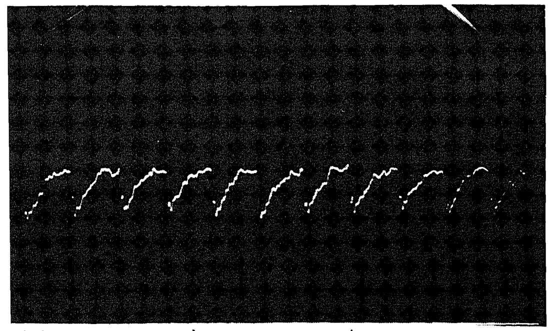


(a) Vert 50 V/D, Horz 3 ms/D

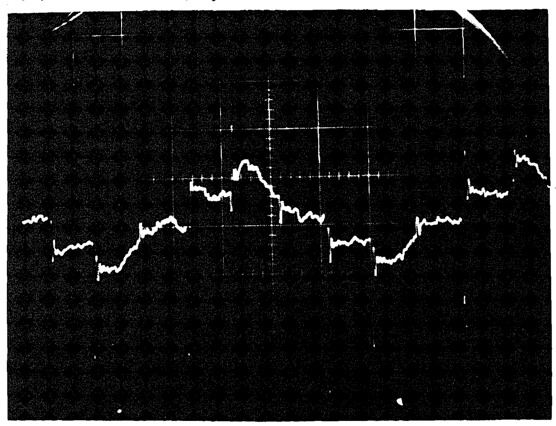


(b) Vert 50 V/D, Horz 3 ms/D

Figure 11. Inverter input voltage (a) and output current (b) during MHD operation for one unit of the line commutated inverter system with no series inductor used. The phase angle is approximately 160°. Note the large amount of noise on the input and output power.

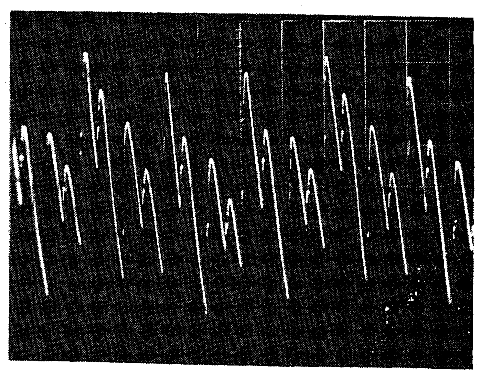


(a) Vert 50 V/D, Horz 3 ms/D



(b) Vert 50 V/D, Horz 3 ms/D

Figure 12. Inverter input voltage (a) and output current (b) during MHD operation for one unit of the line commutated inverter system. A 9-mh inductor is used in series with the input voltages. Note the reduction in noise when compared with Figure 11.



Vert 20 V/D, Horz 3 ms/D

Figure 13. Inverter system total input voltage for 2 units of the line commutated inverter system operating at different phase angles of approximately 130° and 150° using a D.C. power supply. Note the lack of noise in comparison with Figures 11 and 12 and the large fluctuations in the D.C. voltage caused by the use of a smaller phase angle.