A LOW RIPPLE PULSED PHASED BACK POWER SUPPLY*

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Summary. One of the difficult engineering problems of high power pulsed power supplies is to produce a large output voltage range with a low ripple voltage. Phased back rectifier power supplies have sufficient voltage range but suffer from a large ripple content. This paper deals with two methods for reducing the output ripple without the use of a filter. It also includes a non-synchronous firing system for controlling the resulting rectifier.

Introduction

The backleg winding bump coils of the Brookhaven AGS are used to generate local orbit deformation. These deformations provide the versatility needed to target two internal targets simultaneously at different locations.

The bumps are also to be employed in the AGS slow extracted beam to eliminate the need for magnet ramming.

Specifications

In order to minimize lost time in targeting, the bump coils are required to reach the desired field in less than 20 msec. Field fluctuations during the subsequent sustained field, would give rise to a modulation of the beam spill, resulted in a one part in 1000 ripple specification. Because of the inductive nature of the bump coils, the driving power supply must develop 300 volts to produce the desired field rise time. Under the constant field condition a voltage of only 50 volts is required to overcome the IR losses. To accomplish these large voltage variations, as well as to allow for future flexibility in control of the bumps, a phased back SCR controlled rectifier was used as the power supply.

Design Consideration

A phased back rectifier can easily provide large voltage variations. However, a simple six or twelve phase rectifier cannot meet the required ripple specification. Therefore, two new techniques were developed to reduce the ripple output of the supply to the required value. The techniques are as follows:

Center Diodes. Most phase back rectifier used to drive an inductive load, utilize freewheeling diodes to provide a current path for the inductive currents, in case of a power supply failure. If the rectifier is phased back sufficiently, the freewheeling diodes will conduct. This conduction limits the voltage across the load from going negative. The result is that the ripple amplitude is reduced when current flows in the freewheeling diodes. Center diodes, in effect, do the same thing, except they are connected from the center of a WYE connected full wave rectifier (see Fig. 1). When the full wave rectifier is phased back, the voltage from the center of the WYE to the output will attempt to go negative, although the total output is still positive. One of the center diodes will then conduct, converting the full wave rectifier into a half wave rectifier. When the next phase is fired the center diode will stop conducting returning the rectifier to full wave operation. The other center diode will then conduct resulting in a half wave rectifier. The effect is to put the two half wave rectifier, which were in series in the full wave condition, in parallel as far as the voltage output is concerned. The ripple is thereby reduced by a factor of approximately the $\sqrt{3}$. If the center diodes are controlled rectifiers, they can be turned off allowing the power supply to phase back into an invert sequence.

By the addition of two rectifier per six phase unit the ripple output can be reduced by as much as the $\sqrt{3}$, as well as providing a much better power factor for the input power lines.

Twenty-Four Phases. Another method of reducing ripple during phase back operation is to utilize more phases. A practical limit is reached very quickly, however, due to the difficulties of winding polyphase transformers. A twelve phase transformer is easy to construct and does not require tight transformer specification. However, a twenty-four phase transformer running from a standard 3Ø power line is very difficult to balance. It is, therefore, advantageous to utilize a different approach in obtaining the desired twenty-four phase ripple, during phase back operation. Such an approach is the use of two inphase twelve phase rectifiers. Twenty-four phase ripple is obtained by changing the firing order of the two inphase rectifiers. Two phase from one rectifier are fired in order and then two from the second rectifier. The firing occurs as if the whole system was a twenty-four phase rectifier (see Fig. 2). The output from the interphase transformer has a ripple content, in a phased back condition, as if it were a true twenty-four phase rectifier. As the rectifiers are phased nearer full rectify, the twenty-four phase ripple degenerates into twelve phase ripple, characteristic of the original twelve phase rectifier. Two identical twelve phase rectifiers in parallel by the use of an interphase transformer operate not only to provide parallel current paths but also reduce the output voltage ripple.

Composite Rectifier. When the above two techniques are combined into one rectifier the result is a voltage ripple content versus dc voltage as indicated in Fig. 3. The output ripple

* Work done under the auspices of the U.S. Atomic Energy Commission.

is fairly uniform during phase back operation and it is sufficiently small to meet the one part in 1000 current ripple specification.

Nonsynchronous Firing System

To provide the firing pulses for this more complicated type of rectifier a new approach was used. Conventional systems utilize the input line voltages to derive the desired firing pulses. The new system obtains its firing information from the dc output voltage directly and, therefore is called a nonsynchronous system. It operates on the principle that the firing order is a fixed ordered set. Independent of the desired output voltage a given phase firing always follows a prescribed phase. If the time of firing is knowing, the correct phase will be fired, since the knowledge of the last firing determines the proper phase to fire. The selection of the proper phase to fire is made by a simple counter-decoder which is incremented every time a firing pulse is generated. The time to fire is generated when the output voltage becomes negative with respect to the control signal (see Fig. 4). Firing pulses are then generated until the output becomes positive with respect to the control signal. The result is a self-synchronizing firing system. The bottom of the ripple output is thereby equal to the control signal. The firing systems advantages are its simplicity as well as its reduction of sub-harmonic ripple due to the transformer misbalance.

Results and Conclusions

A typical voltage and current waveform is given in Fig. 5. The ratio of the maximum rate of rise of current to the maximum peak to peak ripple current for the supply is 62,000 which is about a factor of seven better than a conventional twelve phase power supply. A current of 1000 amperes can be produced in the backleg winding bump coils in less than 20 msec with a peak to peak ripple current of less than 0.8 amperes. The result is a power supply capable of fast current rise times and low ripple currents with no extra filtering.

It is clear then that with ripple reducing techniques the SCR controlled phased back rectifier can be used very effectively for driving pulsed inductive loads.

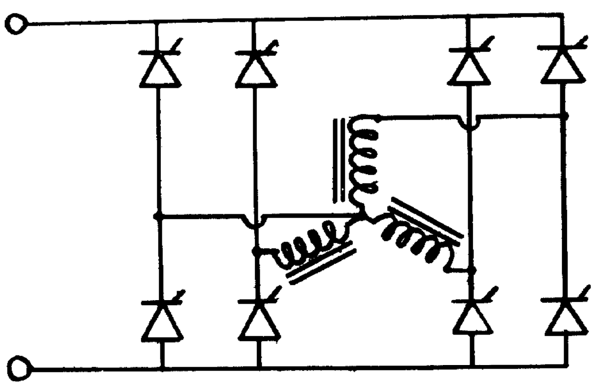

Fig. 1a. Rectifier Connection for Center Diodes.

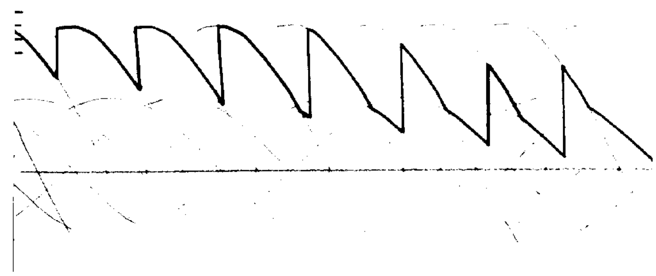

Fig. 1b. Voltage wave forms for a 6 phase full wave rectifier with center diodes.

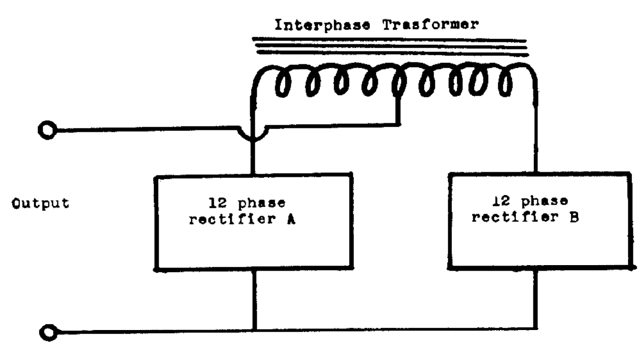

Fig. 2a. Connections for 2 Inphase 12 Phase Rectifiers.

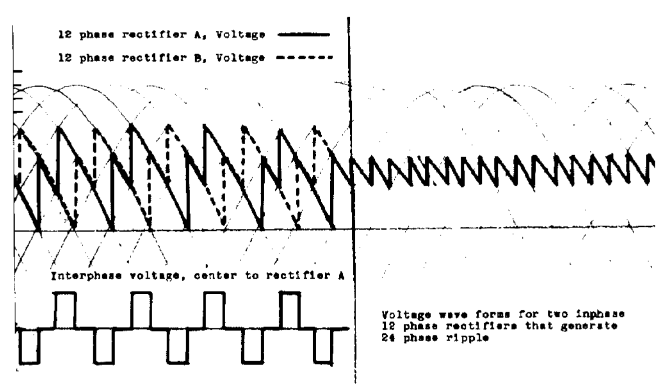

Fig. 2b. Output from interphase transformer.

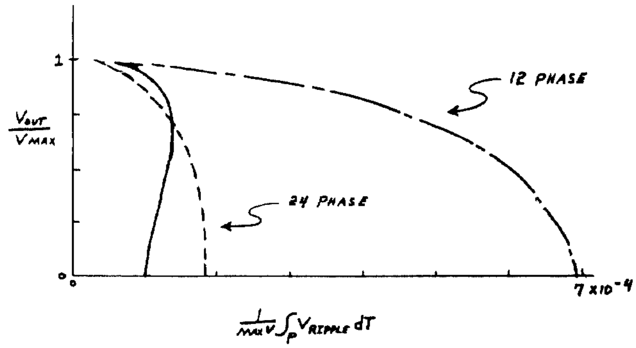

Fig. 3a. D.C. Output Voltage to Ripple Current.

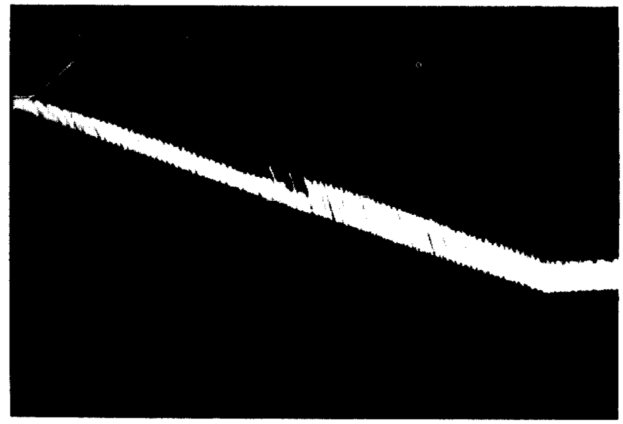

Fig. 3b. Output Voltage at Supply with
Ramp Input
5 msec per Division
100 Volts per Division

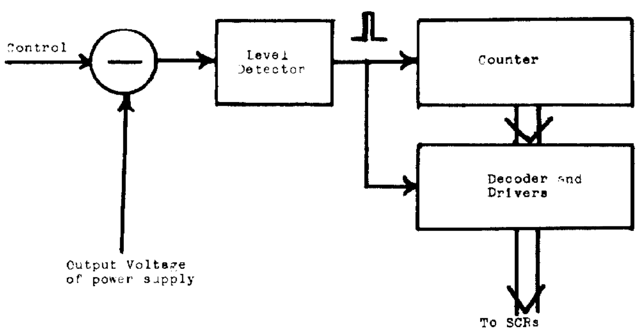

Fig. 4. Nonsynchronous Firing System.

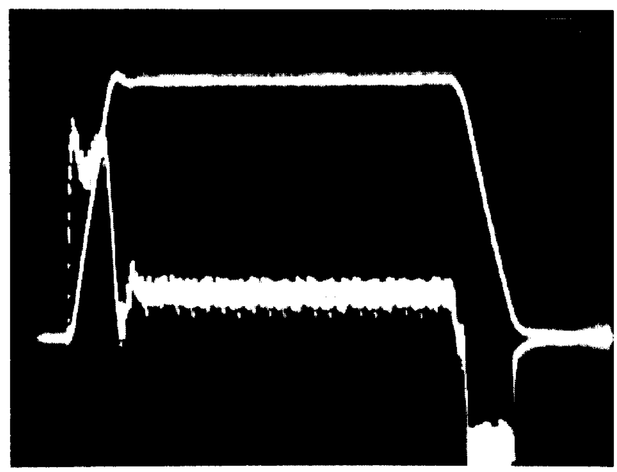

Fig. 5. Output Voltage and Current
20 msec per Division
100 Amps. per Division
50 Volts per Division