Programmable Thyristor Power Supply for Large Capacitor Banks

S. NAGABHUSHANA AND S. KRISHNAN

Abstract—While charging large capacitor banks from a constant-voltage source the initial charging current can be excessively large. Various methods are available to overcome this difficulty such as the use of a series resistor, motorized autotransformers, induction regulators, etc., which have certain disadvantages. This paper discusses a thyristor phase controlled capacitor charging system which enables programmable constant current charging. Further, ample standby power is available at the end of the charging cycle which helps in sustaining the voltage across the electrolytic capacitor banks which have comparatively high leakage.

INTRODUCTION

One of the problems in charging large capacitor banks is high inrush currents at the beginning of the charge and choked current at the completion of the charge. Various methods [1, 2, 3] are used to limit the initial charging current and all the methods aim generally at providing a constant-current charging. The most obvious solution, the inclusion of a series resistor in the charging circuit to limit the charging current, is certainly not the best one. It is inefficient since the resistor will dissipate an amount of energy which is equal to that finally stored in the capacitor bank. Further, at the end of charging when large currents are required to supply the leakage, the least current is available for the capacitors and usually a smaller resistor has to be manually switched in to overcome this difficulty. Motorized regulators are satisfactory, but have obvious disadvantages associated with electromechanical components. This paper describes a thyristor phase controlled dc supply for charging capacitor banks consisting of high leakage electrolytic capacitors. The charging rate is programmable and is set by a single potentiometer.

The programmable power supply makes use of a "soft start" circuit which is commonly used in incandescent lamp control [4]. A detailed analysis of the circuit is presented.

DESCRIPTION

The circuit (Fig. 1) essentially consists of a ramp and pedestal [5] phase controlled thyristor charging circuit modified by the inclusion of a slowly varying pedestal to facilitate efficient charging of the capacitor bank.

Manuscript received April 19, 1973.
The authors are with the Electronics Division, National Aeronautical Laboratory, Bangalore, India.

Zener diode D_1 provides clipped sinewave to provide DC power to the unijunction transistor (UJT) circuit and also to synchronize the UJT triggering to power line frequency. Q_2 is triggered whenever the emitter voltage reaches a value[6]:

$$V_p = \eta V_{BB} + V_D$$

where

V_p emitter peak voltage;
η intrinsic standoff ratio;
V_{BB} interbase voltage;
V_D emitter diode drop.

Capacitor C_2 will charge exponentially towards ηV_{BB} with a time constant $\tau_1 = R_4 C_2$ adjusted to nearly 10 milliseconds (half period at 50 Hz). In the present design τ_1 is 8.2 milliseconds. Assuming $V_p = 0.63 V_{BB}$ triggering occurs at one time constant, i.e., 8.2 milliseconds, almost at the end of half cycle. Thyristor Q_1 consequently conducts for a very short duration and the capacitor bank C_3 receives negligible charge. The pedestal height, the height at which the ramp starts, can be controlled so that the thyristor conduction angle increases gradually charging C_3 more or less at a constant current.

C_1 is charged exponentially by R_2 as shown in Fig. 2(a), and the charging time is controlled by varying R_2. Clamping diode D_2 and R_3 are included to control the pedestal height on a linear ramp (τ_1).

CIRCUIT DESIGN

Timing capacitor C_2 must be charged quickly (i.e., in a small fraction of the ac half period) through R_3 when C_1 is fully charged to approximately ηV_{BB}. This is essential to enable the thyristor to trigger early in the half cycle, point A in Fig. 2(b). A time constant of 1 millisecond is adequate since the thyristor will then trigger as early as 18°. $\tau_2 = R_3 C_2$ provides a 1 millisecond time constant.

When C_1 has reached ηV_{BB}, a certain amount of charge is removed every half cycle (t = 10 milliseconds) from it to charge C_2 and this must be replenished by R_2 from V_{BB}. R_2 is determined by

$$\left(\frac{V_{BB} - 0.7 V_{BB}}{R_2}\right) t \geq 0.7 V_{BB} C_2$$

assuming $\eta = 0.7$, where t = half period, 10 milliseconds at 50 Hz

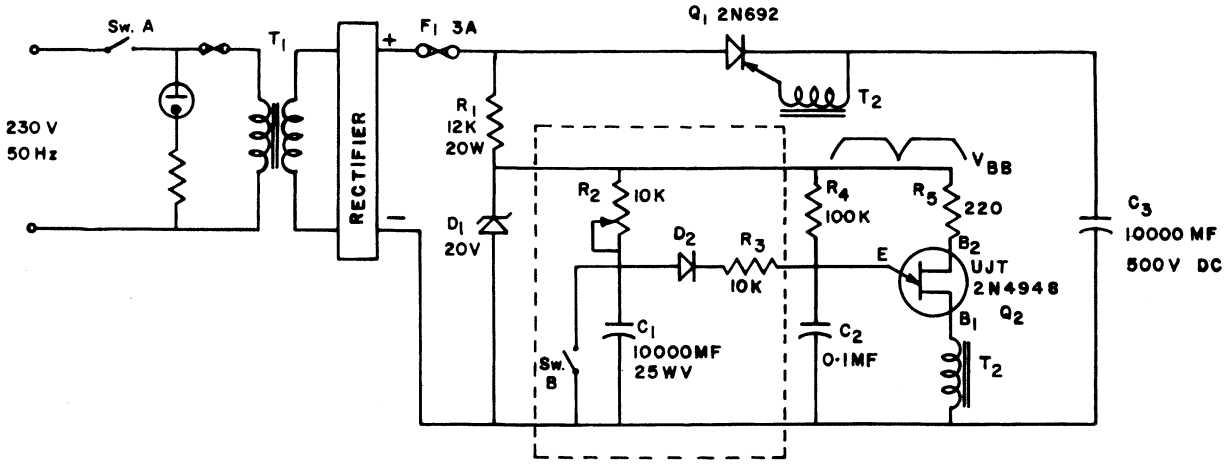

Fig. 1. Programmable power supply for large capacitor banks.

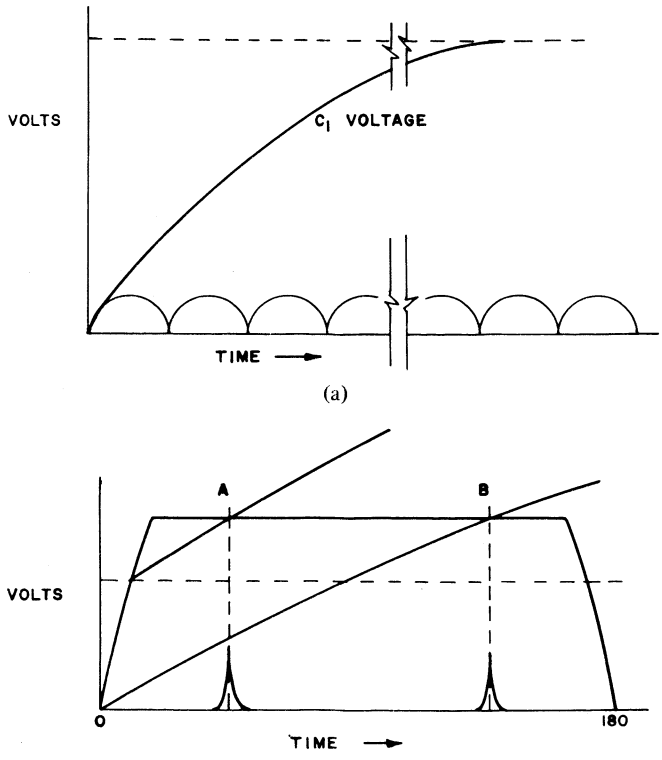

Fig. 2. Voltage across capacitor C_1 is shown at (a) and UJT triggering pulse at (b).

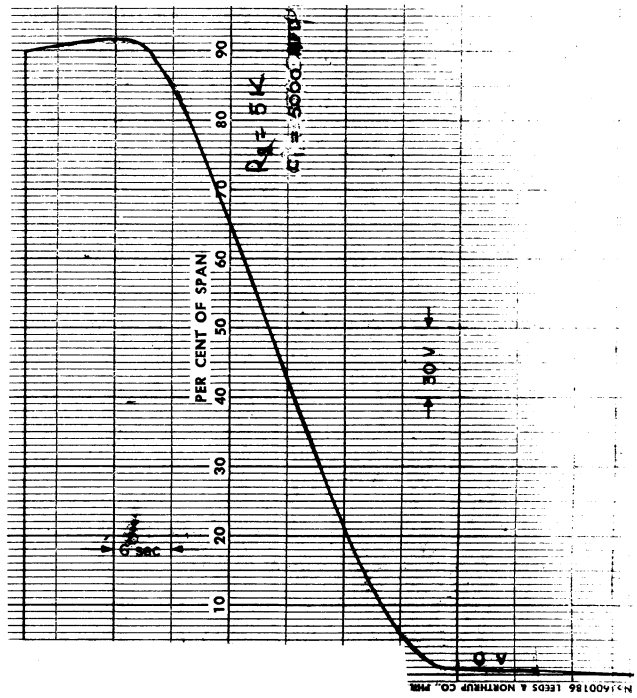

Fig. 3. Chart showing capacitor bank volts vs. time.

$$R_2 \leqslant \frac{0.3t}{C_2}.$$

C_1 can be a large electrolytic capacitor of several thousand microfarads so that R_2C_1 can be of the order of a minute or more. C_1 must of course be reset by *SW-B* for every new charge cycle. Fig. 3 is a typical strip chart recorder output showing the variation of output voltage with time and shows essentially constant current charging. The average current is determined by the slope of this curve and the peak current is measured by an oscilloscope. In the present case, the peak current is 1.8 amps and is very nearly 10 times the average current. The time to charge the capacitor bank C_3 (10,000 mfd, 450 V. dc) is of the order of 36 seconds giving an effective series resistance of 3.6 K. ohms. However if a 3.6 K. ohm resistor were used in place of the charging circuit, it would not be able to supply the leakage current of the capacitors. In other words, such a value cannot be used at least in the latter part of the charging cycle. The power dissipated in this resistor because of leakage current would also be considerable, this being additional to the transient dissipation ($\frac{1}{2}\ CV^2$) during charging. The actual leakage current measured in the setup was 200 milliamps corresponding to a dissipation of 144 watts in the resistor.

CONCLUSION

A thyristor phase control circuit to efficiently charge large capacitor banks has been realized by the ramp variable pedestal technique. The simple low-cost ramp pedestal circuit com-

pletely eliminates the series resistance otherwise required to limit the initial charging current. The effective series resistance by this technique is of the order of several thousand ohms. Adequate current is still available at the end of charging to maintain leakage currents without any large power dissipation.

REFERENCES

[1] Jennings, H. K., *Elec. Eng'g.*, June 1961, p. 419.
[2] Kemp, E. L., *Elec. Eng'g.*, Sept. 1962, pp. 681-685.
[3] Bardos, I., *IEE Conf. Publ. No. 38*, 1967, p. 186.
[4] *Semiconductor Power Circuits Handbook*, Motorola, 1st Ed.
[5] *SCR Manual*, General Electric Co., 3rd Ed.
[6] *Transistor Manual*, General Electric Co., 7th Ed.

An Electronic Switch for the Transient Testing of AC Networks and Machines

VIKTOR POLLAK AND AHMED EL-SERAFI

Abstract—The paper describes an electronic switching device for the transient testing of small ac machines and network models. It is suitable for single-phase or three-phase operation. Precisely timed switching transients can be produced in any or all phases of the tested system. Switching operations in the individual phases can be performed simultaneously or with independent timing. The accuracy of timing is ± 0.5 electrical degree with a timing range from 0 to 2777 cycles. Thyristors are used as the main switching elements. They can continually carry 265 A r.m.s.; the peak inverse voltage across the switching elements is 600V.

Several tests, which have been carried out with the device so far, are described and typical test results are given.

INTRODUCTION

In power systems analysis, the transient performance of the network and of its parts is a point of particular interest. Both the designer and the operator have many reasons, for which they want to know the response of the system to sudden changes in its parameters and its operating conditions. Voltage transients, for example, can be a hazard to the insulation and current transients may cause mechanical damage to windings. Both can give rise to torque transients in rotating machines; these may become especially dangerous if they contain harmonics which are close to the natural frequency of the machine. Adequate knowledge of transient events is also necessary for determining the required level of protection of the system and for the selection of the appropriate protective gear.

Most studies concerned with the transient performance of networks and machines are done analytically. In view of the complexity of even a very small system, analytical procedures have to rely inevitably upon simplifying assumptions. There is, however, frequently some degree of uncertainty, whether the conclusions based upon these assumptions are valid and can be applied in practice. Experimental verification is therefore desirable wherever possible.

Transient tests in real systems are hazardous, time consuming, and costly. Frequently, however, adequate information can be obtained from corresponding tests on suitable models. For instructional purposes, model tests only come into consideration.

For many transient tests, it is highly desirable to be able to perform switching operations on the system at precisely determined instants of the electrical cycle. This gives the experimenter the possibility to study and to determine off-set phenomena, which depend upon the time at which the transient event occurs.

For meaningful results, a high accuracy of timing is essential. Mechanical switchgear falls short of these requirements. Electronic timing together with electronic switching alone are able to provide the needed accuracy. Commercial equipment with the required parameters does not seem to be on the market. It was therefore decided to develop and to build the prototype of a switching device for this purpose in our laboratory. This prototype and some of its applications will be described in this paper. The specifications for the device were set so as to meet the needs of both research and instruction.

Manuscript received June 6, 1972; revised March 5, 1973. This work was carried out under a Grant in Aid of the National Research Council of Canada.

The authors are with the Department of Electrical Engineering, University of Saskatchewan, Saskatoon, Sask., Canada.