Regulated 1,600-Ampere

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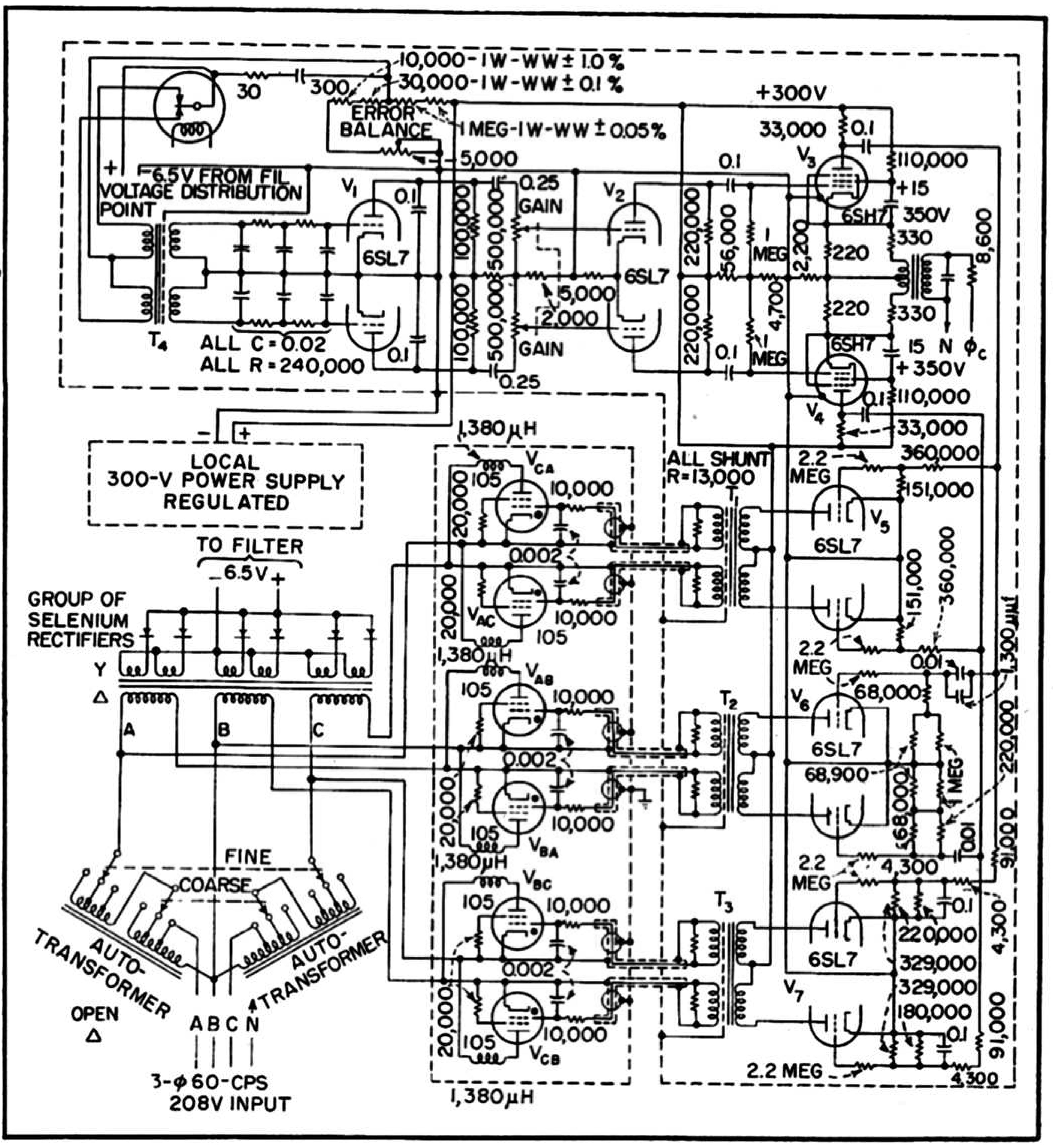

FIG. 1—Circuit used to regulate filament voltage in Project Typhoon analog-digital computer built by RCA for the U. S. Navy

THE POWER SUPPLY to be described was modified from a plating rectifier unit rated at 6 volts d-c at 2,000 amperes, to include a pair of type 105 thyratrons back-to-back in series with each primary of the three-phase transformer, with suitable apparatus for grid phase-control of these thyratrons. The banks of selenium rectifiers were corrected for three-phase full-wave operation and suitable filtering added.

To obtain phase shift for output voltage control, the error signal is chopped at a 60-cycle rate using one phase only on one d-c/a-c converter since a high degree of regulation is not considered necessary. Tube pair V_3-V_4 feeds with equal drive tubes V_5, V_6 and V_7 used as grid limiters. The circuit is so arranged that a sinusoidal voltage introduced into the cathode-to-ground circuit of pair V_3-V_4 produces a voltage across each secondary of the transformers in the output circuits of tubes V_5, V_6 and V_7 of substantially square waveform and of 40 volts amplitude. Tube V_5 operates without phase shift, tube V_6 with 60 degrees leading phase shift and tube V_7 with 60 degrees lagging phase shift.

By reversing a secondary winding of T_2 or T_3 relative to one of T_1, a secondary voltage obtained from T_2 will lag that of T_1 by 120 degrees and that obtained from T_3 will lead that of T_1 by 120 degrees. Thus, when properly related, the six secondaries of T_1, T_2 and T_3 give square waves of equal amplitude and of 60-degree separation. These voltages are of fixed phase relative to the sinusoidal voltage introduced in the cathode circuit of pair V_3-V_4.

Phase shift is now obtained by converting the error voltage, or a difference voltage, from its d-c value to a square-waveform value, filtering it to reduce the harmonics in the network preceding tube V_1, amplifying in V_1, further filtering it in the plate circuit of V_1 and amplifying the substantially sinusoidal voltage of V_2. This resultant sinusoidal voltage is then introduced into the grid-to-ground circuit of tube pair V_3-V_4.

The voltage reference used is obtained from a local regulated +300 volt supply that is itself referenced to a glow tube. The voltage is divided down to operate against the voltage obtained from the filament supply output voltage at the distribution point. Thus, the difference between the reference voltage and the filament voltage is the error voltage. This difference or error voltage is connected between the center arm of the converter contacts and the center-tap of input transformer T_4. Triple shielding on this transformer was used to reduce the magnetic pickup present due to the close proximity of the power transformers.

Figure 2 shows how the error or difference voltage controls the regulation by controlling the firing time of the thyratrons. Since all thyratrons operate identically but 60 degrees apart, only the voltages on a particular thyratron V_{AC} are shown. In the figure only the line voltage e_{AC} is drawn to scale. All phase relations are referenced to this line voltage for convenience. The tube designation V_{AC} is meant to denote that this tube conducts some time while voltage E_{AC} is positive.

For phase rotation, leg voltage *C-N* (e_{CN}) lags line voltage e_{AC} by 30 degrees and leg voltage *A-N* (e_{AN}) lags the *C-N* leg by 120 degrees. Since voltage e_{AC} is going positive, it is desired that the grid

Filament Supply

Moderate degree of regulation required for heating 6-volt filaments of some 4,000 tubes in a computer is provided. Error signal acts through chopper, amplifier and grid limiters to control firing time of thyratrons in primary legs of three-phase transformers

voltage on tube V_{AC} be negative until V_{AC} is to be triggered, at which time it should rise rapidly. Since the square-wave voltage present at the secondaries of transformer T_1 will be in phase with e_{CN}, one of these secondaries is chosen and so polarized that its voltage e_{CN} will go positive at 30 degrees. This will allow conduction of V_{AC} even earlier in the e_{AC} cycle if the output voltage is low, as will be seen.

Now, suppose a positive difference or error voltage exists. Then the polarity is chosen so that an a-c voltage e_{AN} in phase with phase A will be applied in the grid circuit of V_3-V_4. The grid-to-cathode voltage on tube pair V_3-V_4 will now be the algebraic sum of the voltages e_{CN} and e_{AN}, giving voltage e_P. The square-wave voltage e_P' will now be obtained instead of e_{CN}', so that thyratron V_{AC} will be fired 10.9 degrees later.

Actually, a sinusoidal voltage of approximately 110 volts peak to peak is maintained between the plate of V_3 or V_4 and ground. Exaggerated magnitudes of error are chosen for clarity of illustration in Fig. 2 since the principle is the same. Normal regulation occurs at much smaller error amplitude. For example, an error of 0.01 volt introduced across the converter input gives a peak-to-peak sinusoidal voltage of approximately 120 volts between the plate of V_3 or V_4 and ground with no a-c introduced into the cathodes of V_3-V_4.

Thus, if e_{AN} has a maximum amplitude A which is $+0.2\ C$ where C is the maximum amplitude of e_{CN}, the delay angle will be 10.9 degrees. Also, the resulting maximum amplitude of the resultant voltage e_P will be 0.918 C. The square-wave voltage e_P' is then produced by e_P.

Similarly, if the amplitude A is $-0.2\ C$, giving the voltage shown as $-e_{AN}$ corresponding to an error voltage representing too low an output voltage, the resultant sinusoidal voltage shown as eQ will be obtained which will lead e_{AN} by 9 degrees as will the square-wave voltage eQ' produced by eQ. Voltage eQ will then trigger thyratron V_{AC} earlier and therefore increase the output voltage.

While a definite value of line voltage E_{AC} is shown, this voltage is the principal source of variation which requires adjustment of the time of firing to obtain output voltage control. At starting, the line voltages as well as the output voltage are both low, particularly since the coarse autotransformer is used then, hence the phase shift is considerably leading so that the thyratrons are fully conducting throughout the starting period.

An a-c voltmeter is switched across the thyratron pairs to measure and allow adjustment of the regulating voltage E_r appearing across them. For the 30-degree angle shown as the mean position of

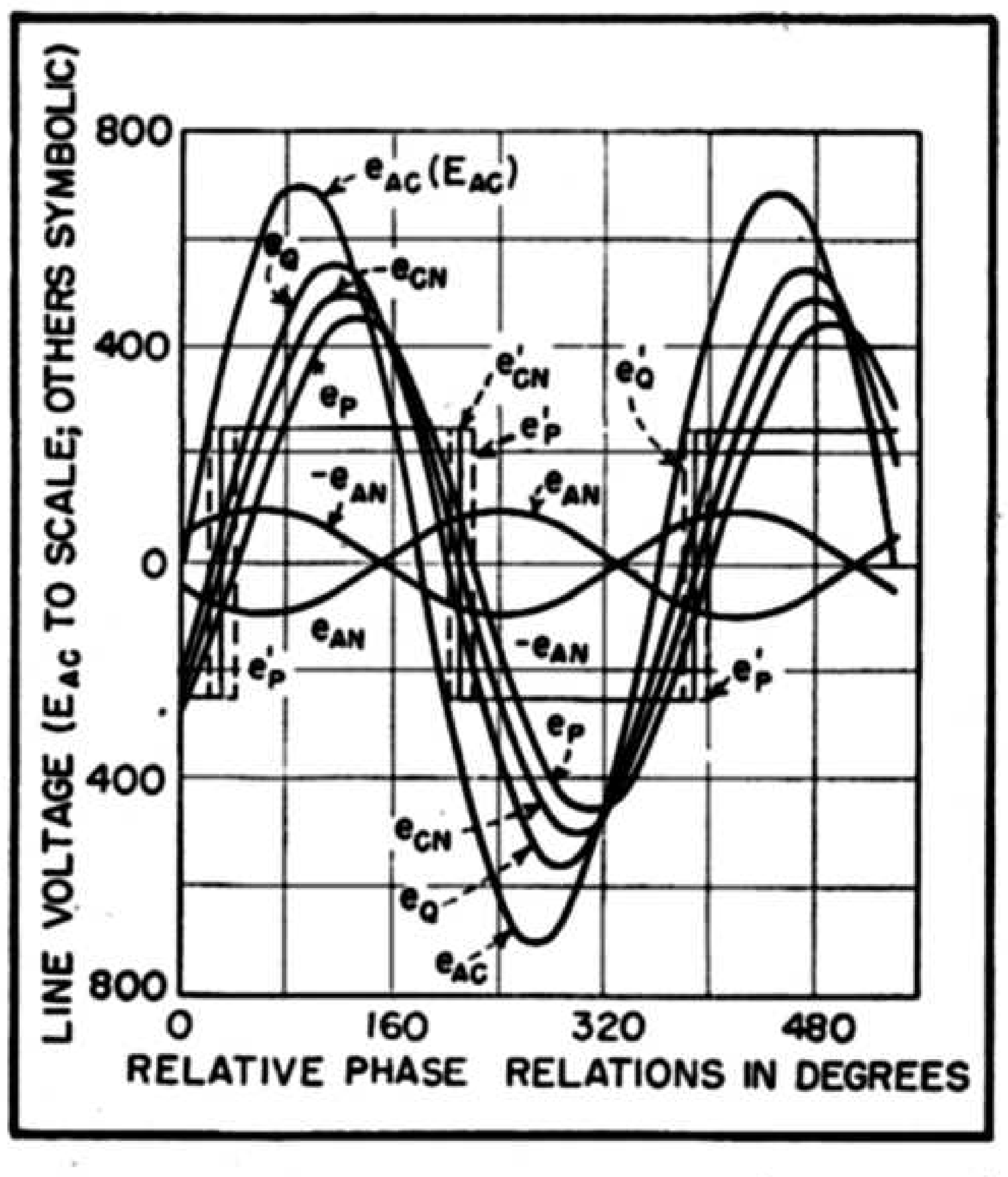

FIG. 2—Firing control curves for one of thyratrons in the circuit

operation in Fig. 2 and the rms value for E_{AC} of $700/\sqrt{2}$ volts, E_r has the value of 84 volts. Actually, for a 1,000-ampere load the measured value of E_{AC} was 495 rms volts and E_r was 70 rms volts. The triggering angle for this condition was therefore slightly less than 30 degrees. The above formula does not take into account tube drop, which is approximately 15 volts during conduction, and waveform distortion which may be appreciable.

To filter the output of the supply, a 0.25-mh reactor having a resistance of 0.1 milliohm and a nominal capacitance of one farad was used. The reactor is of the internal-gap type to minimize external field. The capacitance is considered interesting, not only because of its large value, but also because of the method of mounting the 166 individual capacitors of 6,000 microfarads each on their connecting terminals to minimize lead length. The effective capacitance was greater than one farad in the frequency range where it was desired that it be most effective, due to the inductance of the leads. Measurements at 420 cycles gave an effective capacitance of approximately 1.8 farad and a series resistance of 6.8×10^{-4} ohms.

To test the supply, long strips of Nichrome V four inches wide and 0.03 inch thick were connected in parallel as desired and cooled by fan. After some adjustment of the stabilizing network to the values of 30 ohms and 300 μf shown in series across the error voltage input circuit in Fig. 1, stable regulation was obtained for load values from 25 to 1,680 amperes. The hum level dropped slightly from 4.5 mv for the 25-ampere load to 2.5 mv at full load.