Oct. 29, 1968 J. A. FINGERETT 3,408,554

COMBINED MAGNETIC REGULATOR AND TRANSFORMER

Filed Feb. 28, 1966

4 Sheets-Sheet 1

Fig. 1

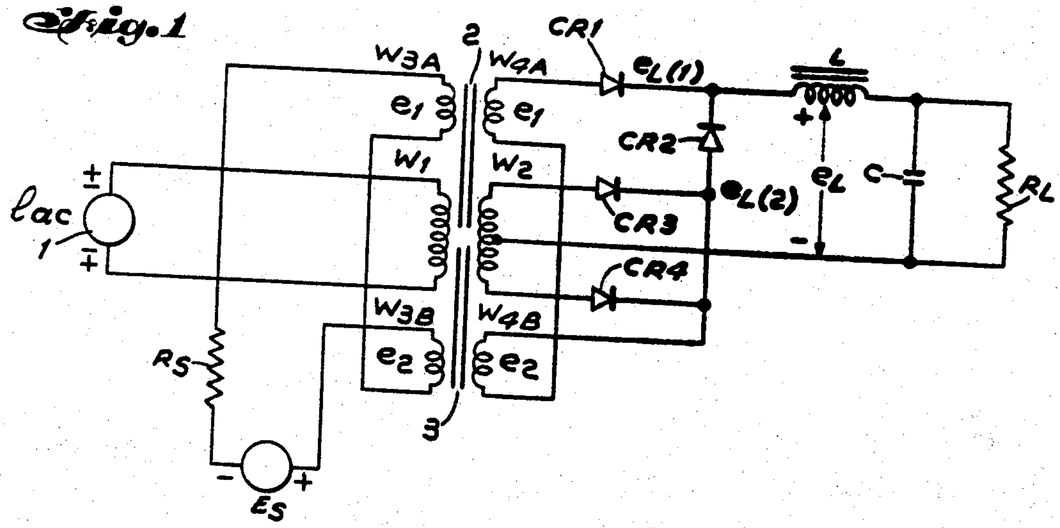
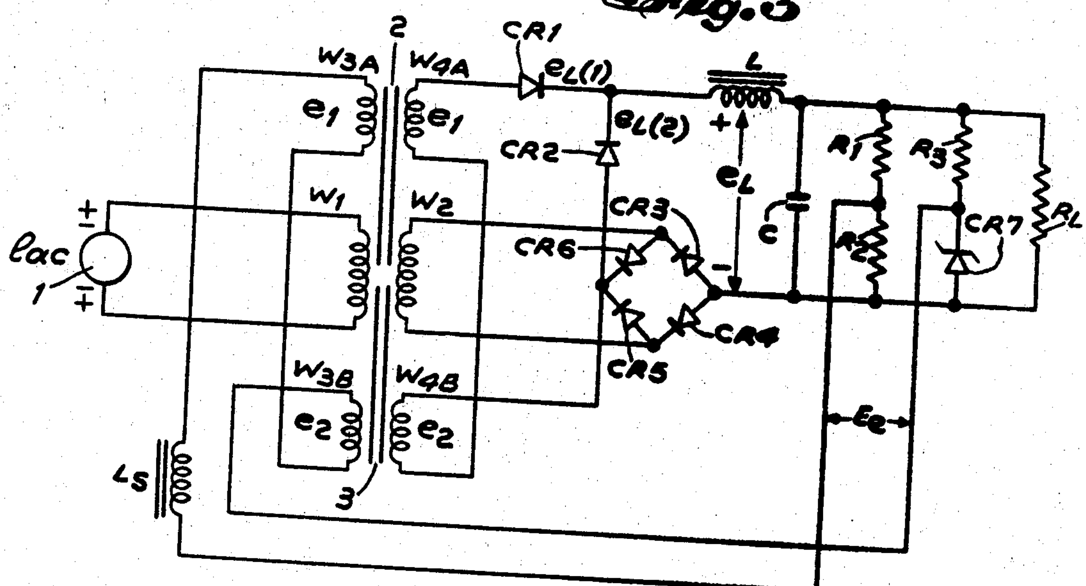


Fig. 3



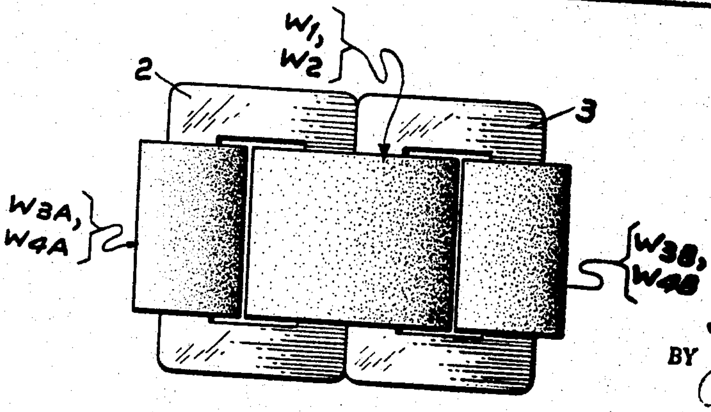


Fig. 4

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Fig. 2

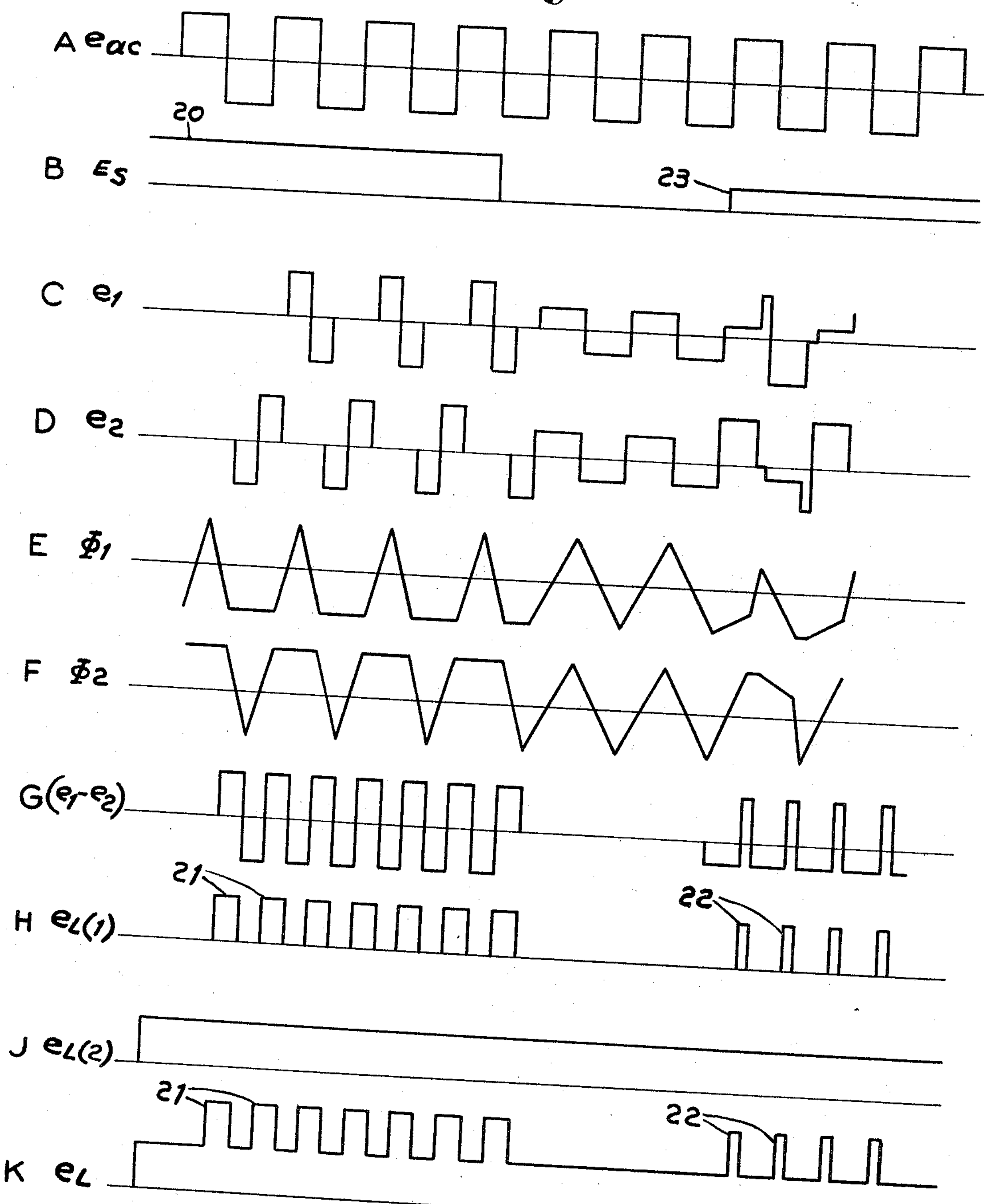

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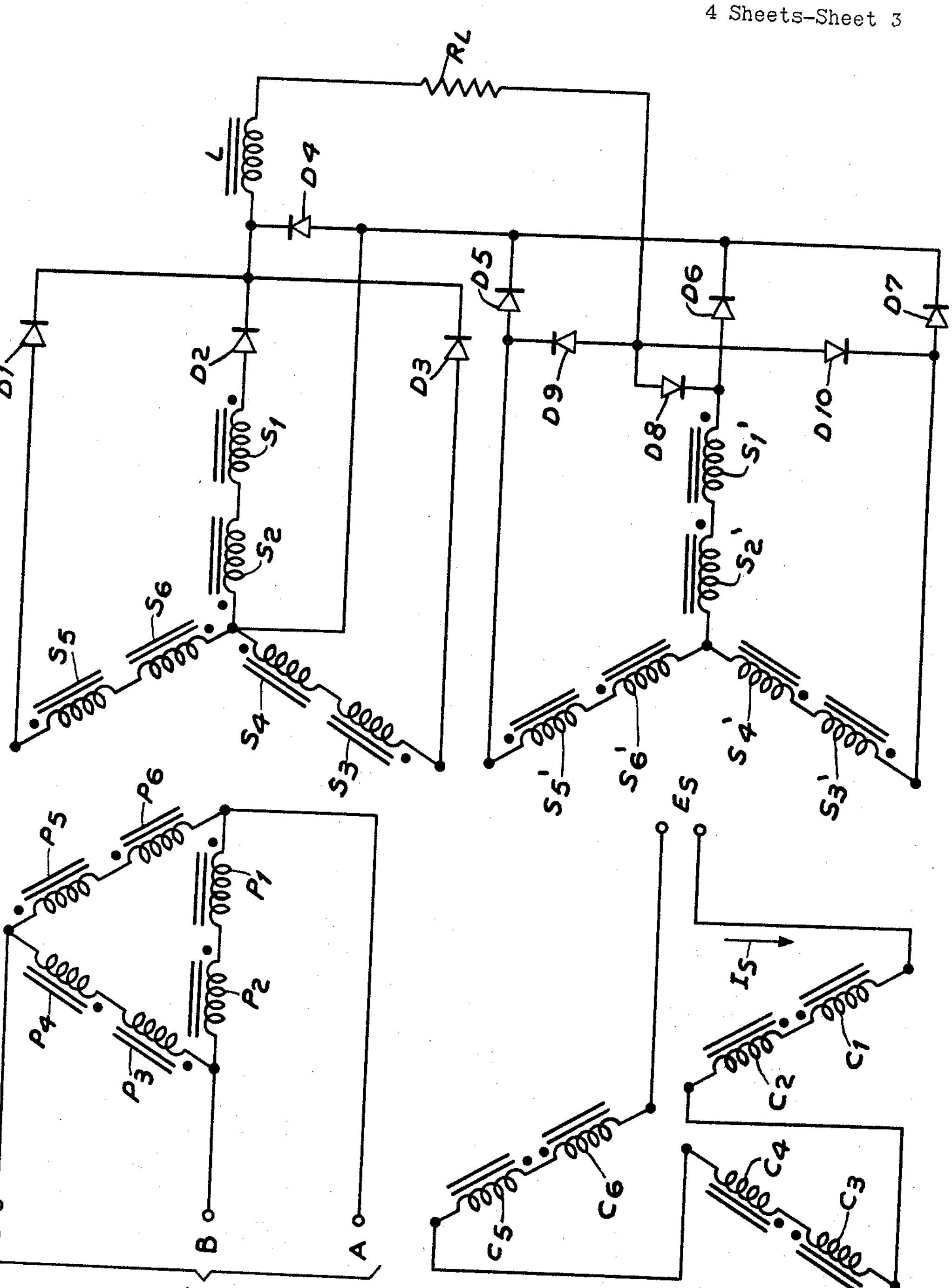
Fig. 5



3-PHASE ALTERNATING CURRENT SOURCE

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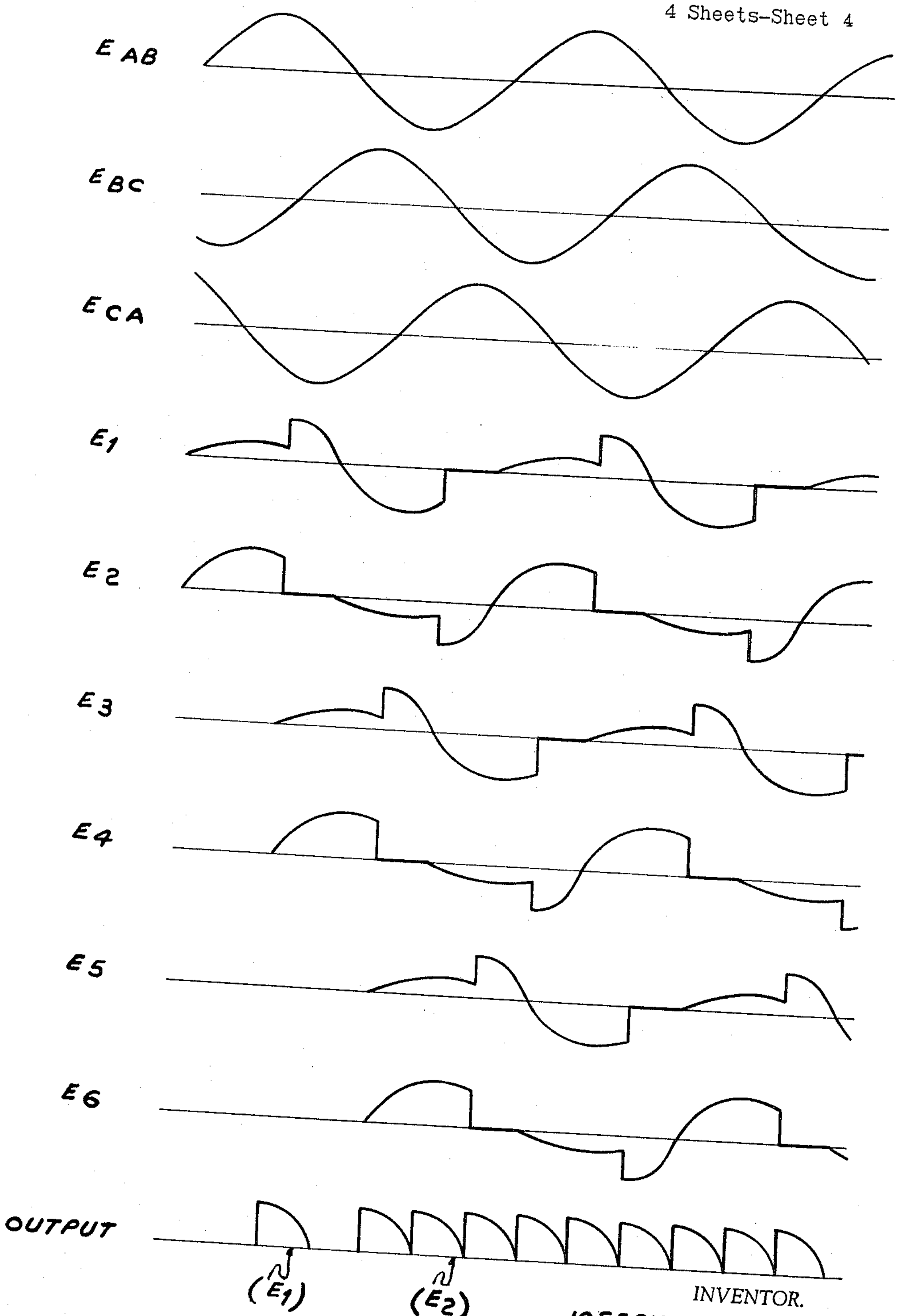

Fig. 6

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3,408,554

COMBINED MAGNETIC REGULATOR AND TRANSFORMER

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11 Claims. (Cl. 321—18)

ABSTRACT OF THE DISCLOSURE

A magnetic regulator compactly combined with a transformer by winding primary and secondary transformer and control windings on two cores, one set of such windings being common to both cores. The secondary winding of the transformer is coupled to the load through a full wave rectifier, a diode and a low pass filter; and the output windings of the magnetic regulator are differentially connected and are further coupled to the load via diodes to maintain the voltage across said load substantially constant regardless of variations in the A.C. input voltage or load impedance.

This invention relates to magnetic regulators and more particularly to a combined magnetic regulator and transformer.

The prior art magnetic regulators normally comprise a transformer coupling the input signal to a series type magnetic regulator. This has the disadvantage of requiring two independent magnetic devices (the transformer and the regulator), and not only adds to the bulk of the system but also adds to the weight and cost thereof.

Therefore, it is the main object of this invention to provide a magnetic regulator combined with a transformer to more efficiently and economically provide a regulated output voltage to a load, said load being either constant or variable.

A feature of this invention is that by winding a common set of windings on two transformer cores the bulk of the system (i.e. the amount of iron required) is substantially decreased over a standard system which uses a separate transformer and magnetic regulator.

The above-mentioned and other objects and features of this invention will become apparent by reference to the following description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic illustration of a magnetic regulator and transformer according to this invention;

FIGURE 2 is a schematic illustration of the waveforms generated at various points in the circuit of FIGURE 1;

FIGURE 3 is a schematic illustration of a feedback-type regulated voltage supply according to this invention;

FIGURE 4 is a representation of the physical structure of the transformer and magnetic regulator according to this invention;

FIGURE 5 is a schematic diagram of a 3-phase circuit according to the principles of this invention, and

FIGURE 6 is an illustration of the waveforms generated at various points in the circuit of FIGURE 5.

Referring to FIGURE 1, an alternating current source 1 is connected to winding W1 which is wound in common onto transformer cores 2 and 3. Windings W3A and W3B are differentially connected and are coupled to a source of D.C. control signals E_S. Winding W2 is wound in common on both transformer cores 2 and 3 in the same manner as winding W1 so that the signal appearing at its terminals

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is the same as the alternating current supply multiplie by either the step-up or step-down ratio between winding W1 and W2. Essentially, the coaction of windings W1 an W2 is the same as in a standard transformer and has n effect on the regulator portion of the circuit. The outpu of winding W2 is coupled to the load R_L via diode CR2 and a full wave rectifier comprising diodes CR3 and CR4. Connected between the full wave rectifier and the load is a low pass filter comprising inductor L and capacitor C. Windings W4A and W4B are differentially connected and are further coupled to the load R_L via diode CR1 in such a manner that the output signal produced thereby is added to the output signal produced across winding W2.

Windings W4A and W4B coupled with the windings on the primary side of said transformers (windings W1, W3A and W3B) operate as a standard magnetic controller, the operation of which is widely known in the art and is described in numerous textbooks and articles (see for example, Magnetic-Amplifier Circuits by Geyger, second edition, pages 264–268). Therefore, a description thereof will not be undertaken here. FIGURES 2A through 2H illustrate the waveforms appearing at various points in the magnetic regulator section of the circuit of FIGURE 1 which comprises windings W1, W3A, W3B, W4A and W4B. The output of the alternating current e_{ac} is shown in FIGURE 2A as a square wave in order to simplify an analysis of the circuit. It is apparent that many other alternating current signals may be utilized instead of a square wave. The terms e_1 and e_2 refer to the voltages across windings W3A and W3B, respectively. Their sum is always equal to the alternating source potential e_{ac}. In the instant embodiment the turns ratio between windings W3A and W4A and between windings W3B and W4B are 1:1. Therefore e_1 and e_2 also represent the voltages across windings W4A and W4B, respectively. Φ_1 and Φ_2 represents the flux in windings W4A and W4B, respectively.

The output of winding W2 is full wave rectified by diodes CR3 and CR4 and is coupled to the load R_L via a diode CR2. The output voltage supplied to the load R_L when $E_S=0$ is merely a full wave rectified version of the alternating input signal. This output is illustrated in FIGURE 2J. When a control signal E_S of a given magnitude is applied, output pulses 21 will be generated across windings W4A and W4B in the same manner as in a standard state-of-the-art magnetic regulator circuit. These pulses 21 are added to the output of the full wave rectifier by means of diodes CR1 and CR2 to generate the signal shown in FIGURE 2K. When E_S is again zero, the output to load R_L is merely the full wave rectified alternating signal (see FIGURE 2K). When E_S has a magnitude less than that of signal 20, pulses 22 of shorter duration than pulses 21 are produced, which pulses are also added to the full wave rectifier output (see signal 23, FIGURE 2B and pulses 22, FIGURES 2H and 2K). It is apparent that as the duration of the pulses produced at windings W4A and W4B increases, the average D.C. voltage supplied to the load increases, and as the duration of the pulses decreases, the average D.C. voltage to the load decreases.

From the above description it is apparent that the circuit of FIGURE 1 may be operated as variable voltage supply. The variation in output voltage is obtained by varying the magnitude of D.C. control signal E_S. As shown in FIGURE 2 when the control signal E_S is decreased (see signal 23, FIGURE 2B) pulses of shorter duration 22 are produced across windings W4A and W4B. This provides a lower average D.C. output voltage than would be obtained when pulses 21 were present, thereby decreasing the D.C. output to the load R_L.

FIGURE 3 illustrates the basic circuit of FIGURE 1 ut further including means for developing an error voltge E_e proportional to the deviation of the output voltage rom a desired value. The error voltage E_e is obtained by neans of the differential coupling of R1, R2, R3 and refernce diode CR7. The junction between resistor R3 and refrence diode CR7 is positive with respect to the junction etween resistors R1 and R2. The D.C. voltage E_e obtained rom this differential connection is applied to windings W3A and W3B in the same manner as was the control signal E_s in FIGURE 1. The operation of this circuit is identical to the operation of the circuit of FIGURE 1. If the voltage across resistor R_L increases, the error voltage E_e will decrease, thereby causing the duration of the pulses added to the output of the full wave rectifier to decrease. This decreases the average voltage supplied to the load. Conversely, when the voltage across R_L decreases, E_e will increase, thereby increasing the duration of the pulses added to the output of said full wave rectifier. In this manner it is seen that the circuit of FIGURE 3 operates as a voltage regulated supply. The circuit of FIGURE 3 utilizes a bridge-type full wave rectifier comprising diodes CR3–CR6 instead of the two diode-type full wave rectifier shown in FIGURE 1. This substitution has no effect on the operation of the circuit and is merely shown by way of example.

FIGURE 4 illustrates a physical embodiment of the transformer and regulator according to this invention. It is seen that windings W1 and W2 are wound in common on cores **2** and **3** to provide the aforementioned advantages. As was previously mentioned, the novel part of this invention lies in the addition of winding W2 to the previously known magnetic regulators and in the manner of placing windings W1 and W2 in common onto two transformer cores. In this manner the amount of iron core required for a given power output is substantially reduced over the prior art circuits which utilize separate regulators and transformers.

In FIGURE 5 there is shown a schematic diagram of a 3-phase circuit according to this invention. Applied to the primary windings P_1 through P_6 is a 3-phase alternating current source. Also wound on the cores are primary control windings C_1 through C_6, to which is applied control voltage E_s. The secondary windings S_1 through S_6, are coupled to load R_1 via diodes D_1 through D_4. Secondary windings S_1' through S_6' are also coupled to load R_1 via diodes D5 through D10 such that the output from windings S_1–S_6 and from S_1'–S_6' are additive at load **R10**. Note that the windings having the same subscripts are wound on the same cores. This circuit operates essentially in the same manner as three single phase structures (as shown in FIGURE 1 for example) coupled together and operating into a common load. In FIGURE 5 secondary windings S_1'–S_6' supply a signal proportional to the alternating input signal to the load. Therefore, the output to the common load R_1 comprises the voltage pulses developed by the regulator portion of the circuit (windings S_1–S_6) superimposed on the full wave rectified version of the input signal which is supplied by windings S_1'–S_6'. Looking at one phase of the circuit of FIGURE 5, it is seen that windings P_1 and P_2, S_1 and S_2, S_1' and S_2' and C_1 and C_2 are analogous to the windings W1, W4A and W4B, W2 and W3A and W3B, respectively, as shown in the circuit of FIGURE 1. Note that in the discussion of the 3-phase system below the alternating current source is a three phase sinusoidal waveform as shown in FIGURE 6A instead of the square wave input shown in FIGURE 2A. It is apparent that any three phase alternating current input signal may be used and that the sinusoidal waveform is shown merely by way of example. A brief description of the circuit shown in FIGURE 5 taken in conjunction with the waveforms shown in FIGURE 6 appears below.

For the purposes of the following discussion it is assumed that windings S_1'–S_6' are not connected in the circuit and the only output signal to the load R_1 is supplied by windings S_1–S_6 via diodes D1–D4. The relationships:

$$(1)\quad E_1 = 4.44\, fN_{(P_1)}\Phi_1\,(\max)$$

$$(2)$$

$$\vdots$$

$$(6)\quad E_6 = 4.44\, fN_{(P_6)}\Phi_6\,(\max)$$

and:

$$(7)\quad E_{1(t)} = KN_{(P_1)}\frac{d\varphi_1}{dt}$$

$$(8)$$

$$\vdots$$

$$(12)\quad (E_{6(t)} = KN_{(P_6)}\frac{d\varphi_6}{dt}$$

will yield

$$(13)\quad \sum_1^6 \varphi_i = 0$$

since

$$E_{AB} + E_{BC} + E_{CA} = 0$$

This merely states that the sum of the fluxes must be zero. This is evident since

$$(14)\qquad E_1 + E_2 = E_{AB} = K(\dot\varphi_1 + \dot\varphi_2)$$

$$(15)\qquad E_3 + E_4 = E_{BC} = K(\dot\varphi_3 + \dot\varphi_4)$$

$$(16)\qquad E_5 + E_6 = E_{CA} = K(\dot\varphi_5 + \dot\varphi_6)$$

Note that Equations 14, 15, and 16 are imposed by the fact that P_1 and P_2 are in series across E_{AB}, etc. During the portion of each cycle that both core segments are unsaturated, a second condition can be imposed (see FIGURE 5).

$$(17)\qquad E_1 - E_2 = f(I_C)$$

The time that Equation 17 is effective is from the zero crossing of the appropriate phase of the supply voltage, until saturation of one flux path of the pair. During this time, the control windings present a relatively high input impedance, and the current flow is related to the differential impedance of two unsaturated cores operating at different voltage levels.

In FIGURE 6, the three phase alternating current supply potential is shown, with typical waveforms for E_1 and E_2, E_3 and E_4, E_5 and E_6 will be pairwise identical, except for the relative phase displacement of the corresponding primary sources. The output resulting from the system is shown, for saturation of the first core in each pair at 120°. It is possible to provide for saturation at any phase angle between 90° and 180°, the corresponding output level going from maximum to minimum. The minimum output obtainable from this circuit is zero.

FIGURE 5 will now be discussed assuming that secondary windings S_1'–S_6' are connected in the circuit as shown. These secondaries are series connected as are the primaries, so that a conventional three phase rectified output is obtained therefrom by means of diodes **D5–D10**. Since windings S_1' and S_2' are coupled together in the same relationship as are windings P_1 and P_2, the voltage across this series pair is related to the primary voltage through the turns ratio used. The differential voltage will not appear across the series pair.

The output obtained from windings S_1–S_6 (see FIGURES 5 and 6) is superimposed onto the output obtained from the full wave rectified output of windings S_1'–S_6'. This represents the three phase equivalent of the single phase circuit previously described with reference to FIGURES 1 and 3.

It should be noted that the output ripple frequency from the three phase controller is at six times the supply frequency, even though only three rectifiers are used. As was previously seen, in the single phase unit the ripple frequency was twice the supply frequency.

It is pointed out that a sensing circuit coupled from the load R_1 to control voltage E_s may be added to this circuit in the same manner as in FIGURE 3 to provide a regulated 3-phase voltage supply. It is not shown in the drawings in conjunction with the 3-phase circuit for the sake of clarity.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention, as set forth in the accompanying claims.

I claim:

1. A combined magnetic regulator and transformer comprising:
   a first transformer core having first and second primary windings and first and second secondary windings;
   a second transformer core having third and fourth primary windings and third and fourth secondary windings;
   said first and third primary windings being coupled in series aiding, said first and third secondary windings being coupled in series aiding, said second and fourth primary windings being coupled in series opposing, and said second and fourth secondary windings being coupled in series opposing;
   means for applying an alternating current (source) to said first and third primary windings;
   output means coupled to said first and third secondary windings;
   means for applying a control signal to said second and fourth primary windings; and
   means coupling said second and fourth secondary windings to said output means to maintain an output voltage proportional to said alternating current and said control signal.

2. A combined magnetic regulator and transformer according to claim 1 wherein said means for applying a control signal comprises:
   means coupled to said output means for developing an error voltage proportional to the deviation of the output signal across said output means from a desired value; and
   means coupling said error voltage to said second and fourth primary windings to maintain said output signal substantially constant.

3. The device of claim 2 wherein said means for developing an error voltage comprises a differential voltage detector coupled across said output means.

4. The device of claim 3 wherein said differential detector comprises:
   first and second resistors coupled in series and across said output means;
   a third resistor;
   a voltage reference diode;
   means coupling said third resistor and said reference diode in series and across said output means; and
   means for deriving said error voltage across the connection between said first and second resistors and the connection between said third resistor and said reference diode.

5. A combined magnetic regulator and transformer comprising:
   a first transformer core having first primary windings and first secondary windings thereon;
   a second transformer core having second primary windings and second secondary windings thereon;
   third primary and third secondary windings wound in common on both of said cores;
   means for applying an alternating current signal to said third primary windings;
   output means coupled to said third secondary windings;
   means for applying a control signal to said first and second primary windings; and
   means coupling said first and second secondary windings to said output means to maintain an output voltage proportional to said alternating current signal and said control signal.

6. A combined magnetic regulator and transformer comprising:
   a first transformer core having first and second primary windings and first and second secondary windings thereon;
   a second transformer core having third and fourth primary windings and third and fourth secondary windings thereon;
   means for applying an alternating current signal to said first and third primary windings;
   a full wave rectifier coupled to said first and third secondary windings;
   a first diode coupled to the output of said full wave rectifier;
   a low pass filter coupled to said diode;
   an output utilization means;
   means for applying a control signal to said second and fourth primary windings; and
   means coupling said second and fourth secondary windings to said low pass filter to maintain an output voltage proportional to said alternating current signal and said control signal.

7. The device of claim 6 wherein said means coupling said second and fourth secondary windings to said low pass filter comprises a second diode, one end coupled to said second and fourth secondary windings and the other end coupled to the connection between said first diode and said low pass filter.

8. A combined 3-phase magnetic regulator and transformer comprising:
   a first transformer core having first and second primary windings and first and second secondary windings;
   a second transformer core having third and fourth primary windings and third and fourth secondary windings;
   means for applying one phase of a 3-phase alternating current signal to said first and third primary windings;
   a third transformer core having fifth and sixth primary windings and fifth and sixth secondary windings;
   a fourth transformer core having seventh and eighth primary windings and seventh and eighth secondary windings;
   means for applying a second phase of a 3-phase alternating current signal to said fifth and seventh primary windings;
   a fifth transformer core having ninth and tenth primary windings and ninth and tenth secondary windings;
   a sixth transformer core having eleventh and twelfth primary windings and eleventh and twelfth secondary windings;
   means for applying the third phase of a 3-phase alternating current signal to said ninth and eleventh primary windings;
   means for applying a control signal to said second, fourth, sixth, eighth, tenth and twelfth primary windings; and
   output means coupled to said secondary windings, said output means being supplied with an output signal proportional to said alternating current signal and said control signal.

9. The device of claim 8 wherein said first and third primary windings are coupled in series aiding, said fifth and seventh primary windings are coupled in series aiding, said ninth and eleventh primary windings are coupled in series aiding, said second and fourth primary windings are coupled in series opposing, said sixth and eighth primary windings are coupled in series opposing, said tenth and twelfth primary windings are coupled in series opposing, said first and third secondary windings are coupled in series aiding, said fifth and seventh secondary

windings are coupled in series aiding, said ninth and eleventh secondary windings are coupled in series aiding, said second and fourth secondary windings are coupled in series opposing, said sixth and eighth secondary windings are coupled in series opposing and said tenth and twelfth secondary windings are coupled in series opposing.

10. The device of claim **9** wherein said first, third, fifth, seventh, ninth, and eleventh primary windings are coupled in a 3-phase delta configuration, said second, fourth, sixth, eighth, tenth, and twelfth primary windings are coupled in series and to a D.C. control signal, said first, third, fifth, seventh, ninth and eleventh secondary windings are coupled together in a 3-phase Y configuration and said second, fourth, sixth, eighth, tenth and twelfth secondary windings are coupled together in a 3-phase Y configuration.

11. The device of claim **10** further comprising a plu-

rality of diodes, each endpoint of the legs of said Y configurations and each neutral point of said Y configurations being coupled to said output means via one of said plurality of diodes.

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