March 7, 1933.

B. D. BEDFORD

1,900,538

PHASE SHIFTING CIRCUITS

Filed Aug. 27, 1930

Fig. 1.

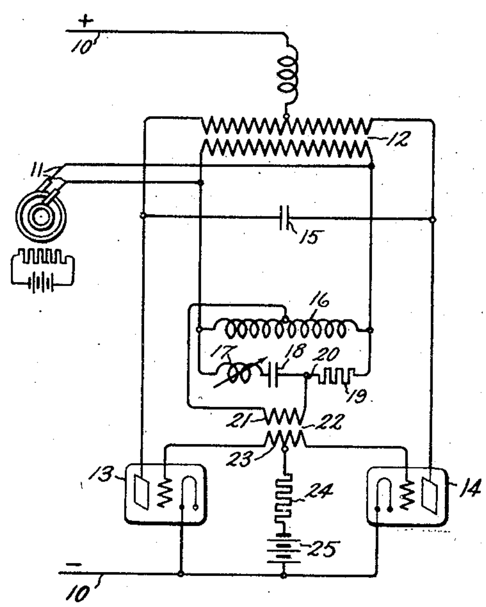


Fig. 2.

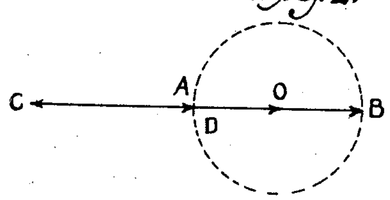


Fig. 4.

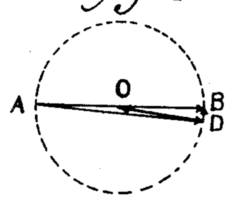


Fig. 3.

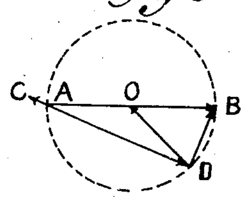


Fig. 5.

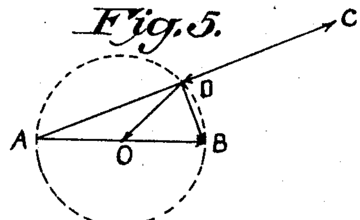
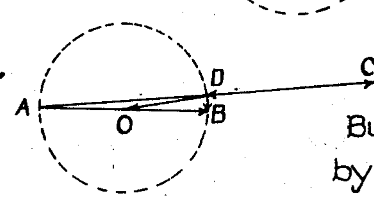


Fig. 6.



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Patented Mar. 7, 1933

1,900,538

UNITED STATES PATENT OFFICE

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PHASE SHIFTING CIRCUITS

Application filed August 27, 1930. Serial No. 478,165.

My invention relates to electric circuits for shifting the phase of an alternating potential derived from a source with respect to the potential of that source and more particularly to such electric circuits by means of which a shift in phase of nearly 360° may be obtained by variation of the circuit elements within practical limits.

My invention is of general application in electric control and regulating systems although it is particularly adapted for use in connection with electric power converting apparatus for transmitting energy between direct current and alternating current systems, or between two alternating current systems, by the use of electric valves. In such apparatus it is customary to control the transmission of power between the direct current and alternating current systems by shifting the phase of the potentials applied to the control grids of the valves with respect to the anode potentials. Various arrangements have been provided heretofore to effect this phase shift of the grid potentials. Static phase shifters, that is, electric circuits including various combinations of resistance, reactance and capacitance, have proved to be most satisfactory from the standpoint of simplicity, economy, and reliability. In the static phase shifting circuits heretofore devised, it has been necessary to vary one of the circuit elements from zero to infinity in order to obtain a phase shift of 180°, while in some instances it is desirable to obtain a phase shift of more than 180° in order to provide the maximum flexibility in the control of the power converting apparatus. Obviously such a wide variation in a circuit element is a practical impossibility, and even in order to secure a reasonable range of phase shift it has been necessary to vary the circuit elements over extremely wide limits.

It is an object of my invention to overcome the disadvantages above noted in connection with static phase shifting circuits and to provide such a circuit in which the desired phase shift of more than 180° can be secured without extreme variation in the circuit elements.

It is a further object of my invention to provide a static phase-shifting circuit by means of which a shift in phase of nearly 360° can be obtained by a moderate variation of only one of the circuit elements.

According to my invention I provide a pair of parallel electric circuits; one of these circuits comprises an impedance element or any other means for establishing a point of mid-potential; the other circuit comprises a resistor, a capacitor and a reactor, either the capacitor or reactor, preferably the latter, being variable. For the most satisfactory operation of my device I have found that it is desirable to make the impedance of the capacitor greater than that of the resistor and the maximum impedance of the reactor, substantially twice that of the capacitor. The output potential is taken from the mid-point of the impedance element and from the connection between the resistor and the capacitor. In this way, the branch of the circuit including the capacitor and the reactor may be made to have either a capacitive or an inductive reactance and, by varying this reactance from zero to its maximum value in either direction, a shift in phase of approximately 180° may be obtained in either direction, giving a total of nearly 360° phase shift.

For a better understanding of my invention together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out with more particularity in the appended claims.

Figure 1 of the accompanying drawing is a diagrammatic representation of my invention as applied to an electric power converting apparatus adapted to convert direct current into alternating current, while Figs. 2 to 6, inclusive, are vector diagrams of the voltage relations appearing in my improved phase shifting circuit to aid in the understanding of the invention.

Referring to Fig. 1 of the drawing I have illustrated an electric power converting apparatus comprising a direct current circuit

10 interconnected with an alternating current circuit 11 by a transformer 12 and electric valves 13 and 14. The electric valves 13 and 14 may be of any of the several types well known in the art, but I prefer to use vapor electric discharge devices in which the starting of the current through the device is dependent upon the potential of the control grid but in which the current in the device may be interrupted only by reducing the anode voltage below its critical value. A commutating capacitor 15 is connected between the anodes of the electric valves 13 and 14 to facilitate the transfer of current between them. As is well understood by those skilled in the art, the amount of power transmitted between the direct current circuit 10 and the alternating current circuit 11 can be controlled by controlling the phase of the potentials applied between the grid and the cathode of each of the valves 13 and 14 with respect to their anode potentials. In order to control the phase of the grid potentials with respect to the anode potentials I have shown a phase-shifting circuit comprising two parallel circuits connected across the alternating current circuit. The first of these circuits constitutes an impedance element shown as a reactor 16 which serves to provide a point of intermediate potential in the alternating current circuit, preferably a point of mid-potential. The second parallel circuit is made up of a serially connected reactor 17, capacitor 18, and resistor 19. The primary winding 21 of a grid transformer 22 is connected between the mid-point of the reactor 16 and the connection between the capacitor 18 and the resistor 19. The secondary winding 23 of this transformer is provided with a midtap which is connected to the cathodes of the valves 13 and 14 through a current-limiting resistor 24 and a negative bias battery 25, while its terminals are connected to the grids of the electric valves 13 and 14.

The amount of power transmitted from the direct current circuit 10 to the alternating current circuit 11 may be controlled by varying the magnitude of the reactor 17 to vary the phase of the potentials applied to the grids of the valves 13 and 14 with respect to the anode potentials of these valves. The manner in which this shift is effected may be explained more clearly by reference to Figs. 2 to 6, inclusive, which represent the voltage vector diagrams of my improved phase shifting circuit under various operating conditions. In each of Figs. 2 to 6, inclusive, the vector AB represents the voltage across reactor 16, the point 0 corresponding to the potential of the midtap of the reactor; the vector AC represents the voltage across reactor 17; the vector CD represents the potential across the capacitor 18; the vector DB, the potential across the resistor 19; and the vector DO the potential between the midtap of the reactor 16 and the junction point 20; that is, the grid potential of the valves 13 and 14. Assume that the reactor 17 is so adjusted that its reactance at the frequency at which the system is operating is exactly equal to that of the capacitor 18. This condition is represented by the vector diagram of Fig. 2. Under this condition the total impedance of this branch of the circuit is zero and the potential applied to the primary winding 21 of the grid transformer is that of the left-hand portion of the reactor 16 and is, of course, in phase with the alternating potential of the circuit 11. If now the inductance of the reactor 17 be decreased so that the effective reactance in this branch of the circuit is capacitive, the voltage applied to the primary winding 21 will lead the voltage of the alternating current circuit 11 as illustrated by the vector diagram of Fig. 3. When the inductance of the reactor 17 has been reduced to zero, the capacitor 18 is the only effective reactance in this branch of the circuit and if this reactance is very high as compared with the value of the resistor 19, the potential of the point 20 will approach that of the right-hand terminal of the reactor 16 very closely and the potential applied to the primary winding 21 will lead the potential of the alternating current circuit 11 by approximately 180°. The vector diagram of Fig. 4 represents this condition. On the other hand, if the inductance of the reactor 17 be increased so that its reactance is greater than that of the capacitor 18, the reactance of this branch of the circuit becomes inductive and the potential applied to the primary winding 21 will lag behind that of the alternating current circuit 11 as illustrated by the vector diagram of Fig. 5. If the inductance of this reactor 17 be increased to its maximum value, in which position its reactance is preferably substantially twice that of the capacitor 18, the impedance of this branch of the circuit is again very large as compared with that of the resistor 19, the potential of the point 20 will approach that of the right-hand terminal of the reactor 16, and the potential applied to the primary winding 21 will lag behind that of the alternating current circuit 11 by approximately 180°. This condition is represented by the vector diagram of Fig. 6. Thus, it is seen, by a variation in the value of the reactor 17 within practical limits a shift in phase of the grid potential over nearly 360° is easily obtained. The value of the resistor 19 is preferably relatively small, being limited only by the energy consumed when the reactance of the reactor 17 and capacitor 18 is equal to zero.

While I have shown and described what I at present consider the preferred embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from my invention, and I therefore aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:—

1. In combination with a source of alternating potential means for obtaining a potential variable in phase with respect thereto over a range of more than 180 electrical degrees comprising means for establishing a point of intermediate potential of said source, a two-part series circuit connected across said source comprising respectively a resistance and an inductance and capacitance one of which is variable, and an output circuit connected between said intermediate point and the junction of said two-part circuit.

2. In combination with a source of alternating potential, means for obtaining a potential variable in phase with respect thereto over a range of more than 180 electrical degrees comprising an impedance connected across said source, a two-part series circuit connected across said source comprising respectively a resistance and a capacitance and variable inductance, and an output circuit connected between an intermediate point of said impedance and the junction of said two-part circuit.

3. In combination with a source of alternating potential means for obtaining a potential variable in phase with respect thereto over a range of more than 180 electrical degrees comprising an impedance connected across said source, a two-part series circuit connected across said source, the first part comprising a resistance and the second part comprising a capacitance having an impedance greater than said resistance at the frequency of said source and a serially connected variable inductance having an impedance substantially twice that of the capacitance.

In witness whereof, I have hereunto set my hand this 26th day of August, 1930.

BURNICE D. BEDFORD.