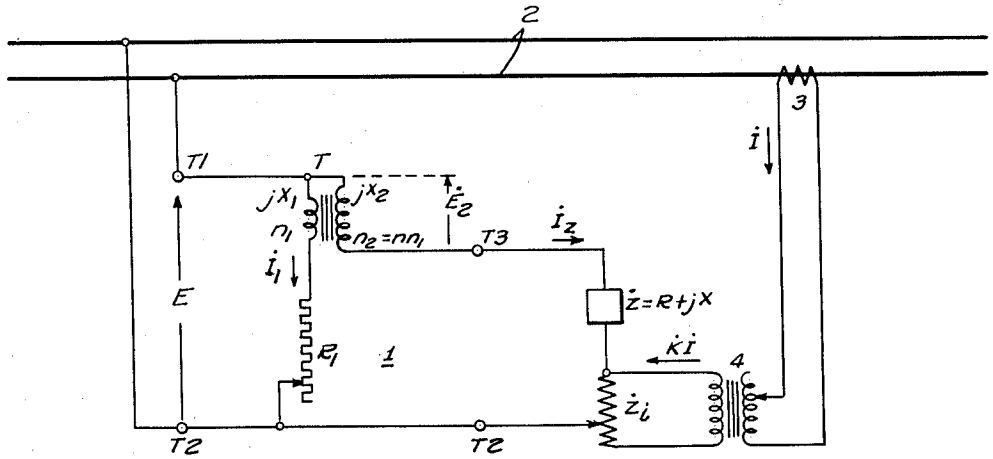
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PHASE SHIFTER

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WITNESSES:

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PHASE SHIFTER

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My invention relates to phase shifting-networks, and it has particular relation to a simple and convenient network for shifting the relative phase-angle between a voltage-responsive input-voltage and a current-responsive (or other voltage responsive) input-voltage, without substantially changing the magnitude. My invention was particularly designed for, and was shown in, the triple-adjustable modified impedance relay of an application of S. L. Goldsborough, Serial No. 547,561, filed August 1, 1944, for Relays, Patent Number 2,393,983, granted February 5, 1946. A significant feature of this Goldsborough relay was the application of two voltage-components to a relay-coil, which was the restraint-coil of a balanced beam impedance-relay, the two voltage-components being responsive, respectively, to the line-current and the line-voltage, with means for varying the magnitude of the current-response, and means for varying the relative phase-angle between the two responses. The phase-shifting means was included in the voltage-responsive energizing-means, in accordance with my present invention.

The object of my invention is to provide a simple and versatile phase-shifting network for accomplishing the purpose just stated.

The accompanying drawing consists of a somewhat simplified and idealized diagrammatic view of circuits and apparatus embodying my invention.

As shown in the drawing, a load-device Z, such as a relay-coil, is supplied with an alternating relaying-current $\dot{I}_Z$ which is supplied from a voltage-responsive source E and from a current-responsive source $\dot{K}\dot{I}\dot{Z}_1$, which is shown as being connected in opposition to the voltage-responsive source, although it could be connected in either polarity. The line-voltage E is applied to the input-terminals T1 and T2 of a phase-shifter network 1 according to my invention, from an alternating-current line 2. Another alternating-current source $\dot{K}\dot{I}\dot{Z}_1$ of the same frequency as the voltage-source E, but of a varying phase-relationship, is provided, and for convenience of reference and illustration, I shall refer to it and illustrate it as a current-responsive source, although it might be another voltage-responsive source, so far as my present invention is concerned. The current-responsive source $\dot{K}\dot{I}\dot{Z}_1$ is represented as receiving energy from the line 2 through a line-current transformer 3, which supplies the line-current $\dot{I}$ to a variable auxiliary

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transformer 4, which supplies the current $\dot{K}\dot{I}$ to an adjustable compensator-impedance

$$\dot{Z}_1=R_1+jX_1$$

My invention has particular reference to the phase-shifting network 1, having output-terminals T3, T2, in addition to the input-terminals T1, T2. The load $\dot{Z}$ and the adjustable compensator-impedance $\dot{Z}_1$ are serially connected across the output-terminals T3 and T2. The network 1 comprises a phase-shifting transformer T and a variable resistor R_1. The transformer T has a primary winding jX_1 having n_1 turns, and a secondary winding jX_2 having $n_2=nn_1$ turns. The primary winding jX_1 and the variable resistor R_1 are connected in series with each other across the input-terminals T1 and T2. The secondary winding jX_2 is connected between the terminals T1 and T3. The resistance of the primary winding jX_1 may be conveniently regarded as being included in the variable resistance R_1, and the resistance of the secondary winding jX_2 is regarded as being included in the load-resistance R of the load impedance $\dot{Z}=R+jX$.

By Thevinin's theorem, the relaying current $\dot{I}_Z$ is given by the equation

$$\dot{I}_Z=\frac{\dot{E}_{eo}-\dot{E}_{io}}{\dot{Z}_s} \qquad (1)$$

where

$\dot{E}_{eo}$=the no-load output-voltage of the voltage-responsive network 1, with no load connected to its output terminals T3 and T2,

$\dot{E}_{io}$=the no-load current-responsive voltage $\dot{K}\dot{I}\dot{Z}_1$, without any connection to the load-device $\dot{Z}$, and

$\dot{Z}_s$=the total impedance, with all voltage-sources short-circuited.

From the drawing, it is evident that the induced secondary voltage due to the primary current $\dot{I}_1$ of the phase-shifting transformer T is

$$\dot{E}_2=jX_M\dot{I}_1=jnX_1\dot{I}_1 \qquad (2)$$

since the mutual reactance, neglecting leakage, is

$$X_M=\sqrt{X_1X_2}, \text{ and since } X_2=n^2X_1 \qquad (3)$$

The primary current $\dot{I}_1$ of the unloaded phase-shifting transformer T is obtained by dividing the impressed voltage E by the primary-circuit impedance, which is

$$Z_pe^{j\phi}=R_1+jX_1 \qquad (4)$$

Therefore, the no-load output-voltage of the voltage-responsive network I is

$$\dot{E}_{oo}=AEe^{j\alpha}=E-\dot{E}_3$$

$$=E-jnX_1\frac{E}{Z_p e^{jp}}=E(1-n\sin p e^{j(90°-p)}) \quad (5)$$

since

$$\sin p=\frac{X_1}{Z_p}$$

from Equation 4, and remembering that $j=e^{j90°}$.

Remembering that $e^{jp}=\cos p+j\sin p$, we may rewrite Equation 5 as

$$\dot{E}_{oo}=AEe^{j\alpha}=E[1-n\sin p(\sin p+j\cos p)]$$

$$=E(1-n\sin^2 p-jn\sin p\cos p) \quad (6)$$

$$=E\left(1-\frac{n}{2}+\frac{n}{2}\cos 2p-j\frac{n}{2}\sin 2p\right) \quad (7)$$

$$=E\left(1-\frac{n}{2}+\frac{n}{2}e^{-j2p}\right) \quad (8)$$

since $\cos 2p=1-2\sin^2 p$, and $\sin 2p=2\sin p\cos p$, and $e^{-j2p}=\cos 2p-j\sin 2p$.

The values of A and α are determinable from Equation 7, from which it is apparent that

$$A=\sqrt{\left(1-\frac{n}{2}+\frac{n}{2}\cos 2p\right)^2+\frac{n^2}{4}\sin^2 2p}$$

$$=\frac{1}{2}\sqrt{4+n^2+n^2\cos^2 2p-4n+4n\cos 2p-2n^2\cos 2p+n^2\sin^2 2p}$$

$$=\frac{1}{2}\sqrt{4+2n(n-2)(1-\cos 2p)}$$

$$=\sqrt{1+\frac{n}{2}(n-2)(1-\cos 2p)} \quad (9)$$

Equation 7 also shows that:

$$\tan\alpha=\frac{-\sin 2p}{\cos 2p-\left(1-\frac{2}{n}\right)} \quad (10)$$

Putting

$$\dot{I}=Ie^{j\theta} \quad (11)$$

and

$$K\dot{Z}_1=Ke^{jk} \quad (12)$$

we may write the no-load current-responsive voltage as

$$\dot{E}_{io}=K\dot{I}\dot{Z}_1=KIe^{j(k+\theta)} \quad (13)$$

Putting

$$\dot{Z}=Z_Z e^{js} \text{ and } \dot{Z}'=Z_Y e^{jy} \quad (14)$$

we may write the total impedance $\dot{Z}_S$ as

$$\dot{Z}_S=Z_S e^{js}=jX_2+\frac{X_1X_2}{R_1+jX_1}+Z_Z e^{js}+Z_Y e^{jy}$$

$$=\frac{jR_1X_2}{R_1+jX_1}+Z_Z e^{js}+Z_Y e^{jy}$$

$$=\frac{jX_2}{1+j\frac{X_1}{R_1}}+Z_Z e^{js}+Z_Y e^{jy}$$

$$=\frac{jX_2}{1+j\tan p}+Z_Z e^{js}+Z_Y e^{jy}$$

$$=\frac{jX_2(1-j\tan p)}{1+\tan^2 p}+Z_Z e^{js}+Z_Y e^{jy}$$

$$=(jX_2+X_2\tan p)\cos^2 p+Z_Z e^{js}+Z_Y e^{jy}$$

$$=X_2\cos p(\sin p+j\cos p)+R+jX+Z_Y e^{jy} \quad (15)$$

$$=X_2\cos p\, e^{j(90°-p)}+Z_Z e^{js}+Z_Y e^{jy} \quad (16)$$

Since the phase-angle s of the total impedance $\dot{Z}_S$ effects the same phase-shift in both the voltage-responsive current-component $\dot{E}_{oo}/\dot{Z}_S$ and the current-responsive current-component $\dot{E}_{io}/\dot{Z}_S$, it does not affect the relative phase-angle between these two components, and hence it does not affect the magnitude of the vectorial sum of said two components.

However, the magnitude Z_S of the denominator $\dot{Z}_S$ in Equation 1 does affect the magnitude of the total relaying-current $\dot{I}_Z$, and hence it is necessary to examine the constancy of the absolute magnitudes of the right-hand side of Equation 16. The total impedance $\dot{Z}_S$ is the vector sum of three vectors, $X_2\cos p\, e^{j(90°-p)}$, $Z_Z e^{js}$ and $Z_Y e^{jy}$. It is quite feasible, and desirable, to make the secondary-winding reactance X_2, and the relay-impedance Z_Z very much greater than the compensator-impedance Z_Y of the current-responsive source $K\dot{I}\dot{Z}_1$, so that the compensator vector-component $Z_Y e^{jy}$ is "swamped." This compensator-impedance $Z_Y e^{jy}$ is subject to variation, when $\dot{Z}_1$ is varied for the purpose of varying the amount of the current-responsive voltage $K\dot{I}\dot{Z}_1$ which is applied to the relay $\dot{Z}$, but since it is only a very small part of the total impedance $\dot{Z}_S$, the resultant variation in $\dot{Z}_S$ is small enough to be neglected.

Neglecting $\dot{Z}_1=Z_Y e^{jy}$, therefore, Equation 16 reduces to

$$\dot{Z}_S=Z_S e^{js}=X_2\cos p\, e^{j(90°-p)}+Z_Z e^{js} \quad (17)$$

$$Z_S=\sqrt{X_2^2\cos^2 p+Z_Z^2+2Z_ZX_2\sin(p+z)\cos p} \quad (18)$$

Or, from Equation 15, neglecting the last term, the magnitude of the total impedance may be expressed as

$$Z_S=\sqrt{(X_2\sin p\cos p+R)^2+(X_2\cos^2 p+X)^2} \quad (19)$$

We may summarize our results, by substitution in Equation 1, showing the relaying current to be

$$\dot{I}_Z=\frac{\dot{E}_{oo}-\dot{E}_{io}}{\dot{Z}_S}=\left[\frac{AEe^{j\alpha}-KIe^{j(k+\theta)}}{Z_S}\right]e^{-js} \quad (20)$$

where A, α and Z_S have the values shown in Equations 9, 10, 18 and 19. The phase-angle between the voltage-responsive voltage-component $AEe^{j\alpha}$ and the current-responsive voltage-component $KIe^{j(k+\theta)}$ is $(\theta+k-\alpha)$, where the effective phase-shift angle α of my phase-shifting network I is as shown in Equation 10.

Considering the magnitude of the voltage-responsive relay-current component $AEe^{j\alpha}/Z_S$, it will be noted that the magnitude-coefficient of this quantity is expressed by the fraction A/Z_S. Neither the numerator A nor the denominator Z_S remains absolutely constant as the primary-circuit impedance-angle p is varied by varying the adjustable resistor R_1, but the departures from constancy are small enough to be within the permissible percentage-error of the relay-response, and the two errors at least partially offset each other, in the line-voltage response, although the error in the constancy of the common denominator Z_S is not compensated in the line-current response $KIe^{j(k+\theta)}/Z_S$.

The denominator Z_S is shown, by Equation 16, to be the resultant of three component vectors, represented by the three terms at the right-hand side of the equation. As previously explained, the third term is small enough, with respect to the other two terms, so that its effect on the

constancy of the resultant impedance-vector may be neglected, or an average value of the third term may be included, if desired, as a part of the constant second term Z_2e^{jk}. The first term, or vector-component, of the total impedance $\dot{Z}_s$ consists of a vector having a magnitude $X_2 \cos p$, and having a phase-angle of $(90°-p)$, where X_2 is the inductive reactance of the secondary winding of the phase-shifting transformer T, and p is the phase-angle of the primary-circuit impedance R_1+jX_1, which is varied by varying the adjustable resistance R_1.

The magnitude of the resultant impedance Z_s can be calculated diagrammatically, utilizing the vectors just discussed, for different values of p, or it may be calculated from either one of equations 18 or 19. For reasonably small values of the primary-circuit angle p, and for values of the relay-impedance Z_z, which are at least approximately commensurate with the secondary-circuit inductance X_2 of the phase-shifting transformer T, the value of Z_s increases by only a small percentage, when p is changed from 0° to 26°, for example.

The variation in the magnitude Z_s will be the least, or substantially least, when its value at $p=o$ equals its value at $p=P$, as p varies between the limits $p=o$ and $p=P$. Making this calculation from Equation 19, we find the value of the load-reactance X, in terms of the load-resistance R, the secondary reactance X_2, and the maximum value P of the primary-circuit impedance-angle p, as follows:

$$X=R\cot P-\frac{1}{2}X_2 \qquad (19a)$$

$$\tan z=\frac{X}{R}=\cot P-\frac{X_2}{2R} \qquad (19b)$$

Thus, if p varied between 0° and 26°, the load-device $\dot{Z}$ would preferably have a reactance X approximating $(2.05\,R-0.5X_2)$. It is not usually necessary to be so particular about the exact phase angle, $z=\tan^{-1}X/R$, of the relay-coil or other load device $\dot{Z}$, so long as the angle-variation p is small.

It is an important feature of my invention, in its preferred form of embodiment, that the primary-circuit impedance-angle p shall be small, preferably not over 30° at its maximum. If

$$p=0°,\ \tan p=\frac{X_1}{R_1}=\text{zero}$$

which is to say that the primary resistance R_1 is infinitely large, or open-circuited. If

$$p=30°=\frac{X_1}{R_1}=0.577$$

which is to say that the variable primary resistance has been reduced to a value equal to 1.732 times the inductive reactance X_1 of the transformer T. In other words, the primary resistance R_1 is very large compared to the primary inductive reactance X_1, and greater than $1.7X_1$.

In an actual embodiment of my invention, which is mentioned only for purposes of illustration, R was 3800 ohms, X_2 was 4550 ohms, X was substantially zero, or negligibly small and p was varied from 0° to 26°. The resultant change in the magnitude of Zs was from 5930 to 6620 ohms, giving an average value of 6275 ohms, with a variation of + or −5.5% from this value.

Let us now consider the constancy of the numerator A of the magnitude-coefficient A/Zs

of the voltage-responsive component $AEe^{j(a-s)}/Z_s$ of the relaying current $\dot{I}_z$ in Equation 20. Equation 9 shows that the variation in the quantity A is contained in the term

$$\frac{n}{2}(n-2)(1-\cos 2p)$$

in which the factor $(1-\cos 2p)$ varies from unity to a rather small value, as the value of p into a rather small value, as the value of p increases above 0°. The factor $(n-2)$ shows that this variation could be made 0, no matter what the value of the angle p, if the transformation-ratio $n=2$. If n is less than 2, the sign of the factor $(n-2)$ becomes negative, so that the coefficient A decreases, instead of increasing, with increasing values of the angle p. If the transformation-ratio n only slightly greater than 2, so that the factor $(n-2)$ is a fraction less than 0.732, the coefficient A increases, with increasing values of the angle p, but at a rate determined by the expression given in Equation 9.

In the aforesaid actual embodiment of my invention, I utilized a transformation-ratio of $n=2.33$, which theoretically made A vary from 1.00 to 1.07, when p varied from 0° to 26°.

These calculations have taken no account of saturation in the iron core of the phase-shifting transformer T, the effect of which would be to reduce the transformer-reactances X_1 and X_2, and also to introduce a leakage-factor reducing the mutual coupling M to a value somewhat less than $\sqrt{X_1X_2}$, as the primary current I_1 was increased in order to increase the primary-circuit impedance-angle p. As these saturation-effects enter into the valuation of both the numerator A and the denominator Zs, they tend to cancel out, although the saturation-effect is somewhat stronger in the numerator.

It will be noted that both the numerator A and the denominator Zs, of the coefficient A/Zs, representing the magnitude-ratio of the response to the line-voltage E, become larger, as p increases from 0° to 26°; the numerator A increasing by 7% of its original value, while the denominator Zs increases by 11.6%, theoretically, in the illustrated example. If the voltage-response were the only consideration, it is obvious that these increases in A and Zs could be equalized, by making a transformation-ratio n slightly larger than 2.33. For example, if it were desired to make the numerator A increase by 12%, when the angle p increased from 0° to 26°, A could be put equal to 1.12 in Equation 9, yielding $n=2.52$. In general, the transformation-ratio n should be between 2 and 2.5.

If, however, any particular application of my invention requires a constant ratio between the current-responsive component KI/Zs, and the voltage-responsive component AEI/Zs, in Equation (20), or a constant ratio K/A, at different values of the phase-shift angle a, then the variation in the coefficient A of my phase-shifting network I would have to be as small as possible, all things considered. In such a case, the first mentioned transformation-ratio, $n=2.33$ would be a better compromise, because it would split the 6% average-error in Zs, (or 12% overall-error), leaving something like the same amount of error in A as in the ratio A/Zs, making A constant within plus or minus 3½%, and A/Zs constant within plus or minus 3%, as the phase-shift angle, a, is adjusted between the limits, 0° and 60°.

Thus, in the previously mentioned Goldsborough application, the relaying-current $\dot{I}_z$ of

my Equation (20) is utilized to produce one of two opposing fluxes in a differential relay (not shown), the other flux being proportional to the line-current $\dot{I}$, or being equal, say, to $gIe^{j\theta}$. The balance-point of the relay occurs when these two fluxes are equal in magnitude, or when

$$Iz=gI \tag{21}$$

From Equation (20), it is evident that Iz is equal to the absolute value of the vector-difference which is included in the brackets. This vector-difference has the magnitude Iz and also some vector-angle, which we may call ϕ. Hence we may express this bracketed quantity as follows, and we may make the substitution shown in Equation (21), yielding

$$\frac{AEe^{j\alpha}-KIe^{j(k+\theta)}}{Z_S}=Iz e^{j\phi} \tag{22}$$

$$=Ie^{j\phi} \tag{23}$$

Dividing through by the absolute value of the line-current I, and remembering that the line-impedance is

$$\dot{Z}_L=\frac{E}{I}=\frac{Ee^{-j\theta}}{I}, \text{ so that } \frac{E}{I}=\dot{Z}_L e^{j\theta} \tag{24}$$

we find, from Equation (23), that

$$\frac{A\dot{Z}_L e^{j(\alpha+\theta)}}{Z_S}=\frac{Ke^{j(k+\theta)}}{Z_S}+ge^{j\phi}$$

$$\dot{Z}_L=\frac{Ke^{j(k-\alpha)}}{A}+\frac{gZ_S e^{j(\phi-\alpha-\theta)}}{A} \tag{25}$$

which is a circle, having a center-displacement

$$\frac{K}{A}e^{j(k-\alpha)}$$

and having a radius gZs/A, at varying values of the linepower-factor angle θ, and at any constant value of the current-response angle k and the voltage-response angle α.

It wil be noted that the displacement-angle of the center of the circle represented in Equation (25) is the angle $(k-\alpha)$ which is the phase-displacement between the voltage-responsive component $\dot{E}_{eo}/\dot{Z}s$ and the current-responsive component $\dot{E}_{io}/\dot{Z}s$ at unity power-factor. Either k or α may be varied; that is, either the phase-displacement α of the voltage-response, or the phase-displacement k of the current-response. The illustrated embodiment of my invention shows the adjustable angle α in the voltage-responsive input of the relay or load-device $\dot{Z}$, but I desire it to be understood that it could have been introduced in the current-responsive voltage $\dot{K}\dot{I}\dot{Z}_l$ instead of the voltage-responsive voltage E.

The variable part of the phase-shift of the voltage-responsive component $\dot{E}_{eo}/\dot{Z}s$, with respect to the current-responsive component $\dot{E}_{io}/\dot{Z}s$ of the relay $\dot{I}z$, as produced by my phase-shifting network I, is the angle α, which is evaluated in Equation (10). From this equation, and also from Equation (8), it is apparent that, when the transformation-ratio n has the critical value of 2, the phase-shift angle α is equal to exactly 2 times the primary circuit impedance-angle p, but opposite in sign. For a 26° variation in the primary angle p, this would yield only a 52° shift in voltage, either leading or lagging with respect to the impressed voltage E, depending upon the polarity of the transformer-connections.

If the transformation-ratio n is made smaller than 2, Equation 10 shows that a definite amount

$$\left(\frac{2}{n}-1\right)$$

is added to the denominator of the fraction representing the tangent of $(-2p)$, regardless of the value p, meaning that the phase-shift angle α will have a numerical angle less than $2p$.

If the transformation-ratio n is greater than 2, the constant quantity

$$\left(1-\frac{2}{n}\right)$$

must be subtracted from the denominator of the fraction representing the tangent of $(-2p)$ in Equation 10, meaning that the phase-shift angle α has a numerical value greater than $2p$. In the numerical example previously given with $n=2.33$, the theoretical value of the phase-shift angle α, neglecting saturation, is 59.1°, when the primary-circuit angle $p=26°$. It is thus seen that an advantage is gained, in the way of a greater range of phase-shift angle α, by making the transformation-ratio n as much greater than 2 as can be tolerated, without introducing too much error in the magnitude-ratio A of the voltage-response or output-voltage of the network.

I claim as my invention:

1. A phase-shifting network for deriving a voltage of a shifted phase and an approximately unchanged magnitude from an alternating-current line which has voltage-supplying means for supplying a line-derived input-voltage which is dependent upon a voltage of the line, substantially unaffected by the impedance of the burden on said voltage-supplying means within the normal burden-range thereof, said network comprising a pair of input-terminals for supplying said input-voltage to the network, a pair of output-terminals, a phase-shifting transformer having a primary circuit and a secondary circuit, an independently variable resistor, said secondary circuit being connected between one of said input-terminals and one of said output-terminals, circuit-connections joining the other output-terminal to the other input-terminal, and circuit-connections for connecting said variable resistor in series with said primary circuit for energization across the two input-terminals, the minimum adjustable value of said variable resistor being greater than 1.7 times the primary inductive reactance of the phase-shifting transformer.

2. A phase-shifting network for deriving a voltage of a shifted phase and an approximately unchanged magnitude from an alternating-current line which has voltage-supplying means for supplying a line-derived input-voltage which is dependent upon a voltage of the line, substantially unaffected by the impedance of the burden on said voltage-supplying means within the normal burden-range thereof, said network comprising a pair of input-terminals for supplying said input-voltage to the network, a pair of output-terminals, a phase-shifting transformer having a primary circuit and a secondary circuit, an independently variable resistor, said secondary circuit being connected between one of said input-terminals and one of said output-terminals, circuit-connections joining the other output-terminal to the other input-terminal, and circuit-connections for connecting said variable resistor in series with said primary circuit for energization across the two input-terminals, the minimum adjustable value of said variable resistor being greater than

1.7 times the primary inductive reactant of the phase-shifting transformer, the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being between approximately 2 and approximately 2.5.

3. A phase-shifting network for deriving a voltage of a shifted phase and an approximately unchanged magnitude from an alternating-current line which has voltage-supplying means for supplying a line-derived input-voltage which is dependent upon a voltage of the line, substantially unaffected by the impedance of the burden on said voltage-supplying means within the normal burden-range thereof, said network comprising a pair of input-terminals for supplying said input-voltage to the network, a pair of output-terminals, a phase-shifting transformer having a primary circuit and a secondary circuit, an independently variable resistor, said secondary circuit being connected between one of said input-terminals and one of said output-terminals, circuit-connections joining the other output-terminal to the other input-terminal, and circuit-connections for connecting said variable resistor in series with said primary circuit for energization across the two input-terminals, the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being between approximately 2 and approximately 2.5.

4. A phase-shifting network for deriving a voltage of a shifted phase and an approximately unchanged magnitude from an alternating-current line which has voltage-supplying means for supplying a line-derived input-voltage which is dependent upon a voltage of the line, substantially unaffected by the impedance of the burden on said voltage-supplying means within the normal burden-range thereof, said network comprising a pair of input-terminals for supplying said input-voltage to the network, a pair of output-terminals, a phase-shifting transformer having a primary circuit and a secondary circuit, an independently variable resistor, said secondary circuit being connected between one of said input-terminals and one of said output-terminals, circuit-connections joining the other output-terminal to the other input-terminal, and circuit-connections for connecting said variable resistor in series with said primary circuit for energization across the two input-terminals, the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being approximately 2.

5. A phase-shifting network for use with an alternating-current line having means for supplying two separate input-voltages to said network from said line, said network comprising a phase-shifting transformer having a primary circuit and a secondary circuit, a variable primary-circuit resistor, circuit-connections for serially connecting said two input-voltages and the secondary circuit of said phase-shifting transformer in series with a load-device, circuit-connections for connecting said variable primary-circuit resistor in series with the primary circuit of said phase-shifting transformer for energization in shunt-circuit relation to one of said input-voltages, and means for independently varying the magnitude of the other input-voltage.

6. The invention as defined in claim 5, characterized by the circuit which includes said secondary circuit of the phase-shifting transformer and the load-device having an impedance which is large enough to swamp any variations in the effective impedance of the second input-voltage when the latter is independently adjusted in magnitude, whereby the total impedance remains substantially constant in magnitude, within permissible limits of error.

7. The invention as defined in claim 5, characterized by the circuit which includes said secondary circuit of the phase-shifting transformer and the load-device having an impedance which is large enough to swamp any variations in the effective impedance of the second input-voltage when the latter is independently adjusted in magnitude, whereby the total impedance remains substantially constant in magnitude, within permissible limits of error, said invention being further characterized by the minimum adjustable value of said variable resistor being greater than 1.7 times the primary inductive reactance of the phase-shifting transformer.

8. The invention as defined in claim 5, characterized by the circuit which includes said secondary circuit of the phase-shifting transformer and the load-device having an impedance which is large enough to swamp any variations in the effective impedance of the second input-voltage when the latter is independently adjusted in magnitude, whereby the total impedance remains substantially constant in magnitude, within permissible limits of error, said invention being further characterized by the minimum adjustable value of said variable resistor being greater than 1.7 times the primary inductive reactance of the phase-shifting transformer, the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being between approximately 2 and approximately 2.5.

9. The invention as defined in claim 5, characterized by the circuit which includes said secondary circuit of the phase-shifting transformer and the load-device having an impedance which is large enough to swamp any variations in the effective impedance of the second input-voltage when the latter is independently adjusted in magnitude, whereby the total impedance remains substantially constant in magnitude, within permissible limits of error, said invention being further characterized by the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being between approximately 2 and approximately 2.5.

10. The invention as defined in claim 5, characterized by the circuit which includes said secondary circuit of the phase-shifting transformer and the load-device having an impedance which is large enough to swamp any variations in the effective impedance of the second input-voltage when the latter is independently adjusted in magnitude, whereby the total impedance remains substantially constant in magnitude, within permissible limits of error, said invention being further characterized by the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being approximately 2.

11. The invention as defined in claim 5, characterized by the minimum adjustable value of said variable resistor being greater than 1.7 times the primary inductive reactance of the phase-shifting transformer.

12. The invention as defined in claim 5, characterized by the minimum adjustable value of said variable resistor being greater than 1.7 times the primary inductive reactance of the phase-shifting transformer, the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being between approximately 2 and approximately 2.5.

13. The invention as defined in claim 5, characterized by the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being between approximately 2 and approximately 2.5.

14. The invention as defined in claim 5, characterized by the phase-shifting transformer having a small leakage between primary and secondary turns, and the ratio of the secondary turns to the primary turns of the phase-shifting transformer being approximately 2.

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