June 19, 1962 J. GOTAL ET AL 3,040,240

POTENTIAL TRANSFORMER

Filed Feb. 20, 1958

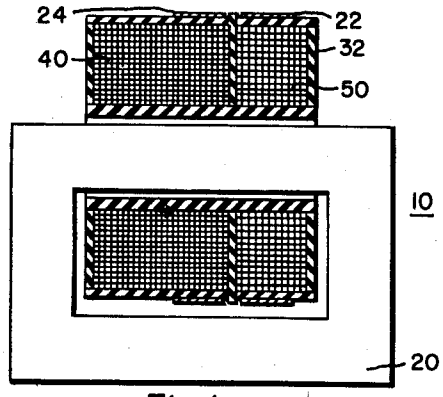


Fig. 1.

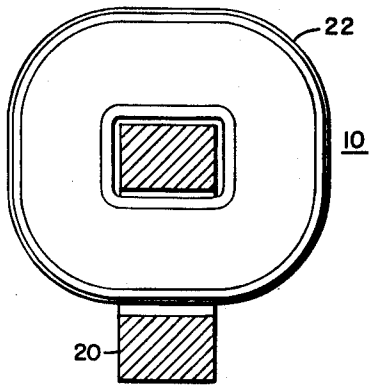


Fig. 2.

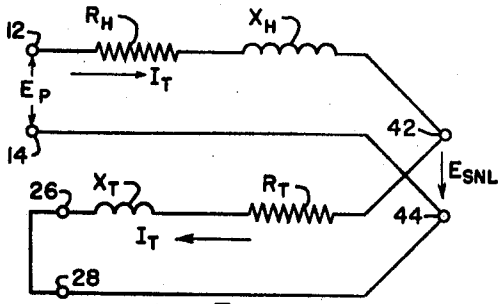


Fig. 3.

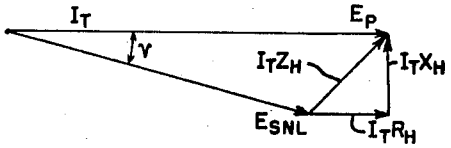


Fig. 4.

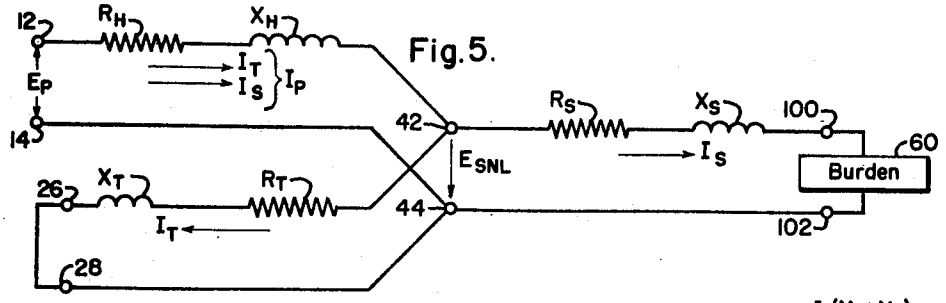


Fig. 5.

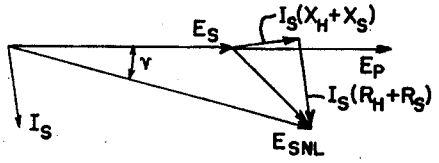


Fig. 6.

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POTENTIAL TRANSFORMER

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This invention relates to potential transformers and, more particularly, to means for reducing or eliminating the phase angle errors in such transformers.

A problem arises in providing certain types of conventional potential transformers for use with burdens having a low power factor. This is because the reactive load current flowing through the resistance of such a transformer produces an out-of-phase voltage drop which introduces a phase angle error between the primary and secondary voltages of the transformer. In order to reduce the phase angle error in such a potential transformer, it is conventional practice to reduce the resistance of the transformer by using larger conductors in the windings of the transformer or, in other words, to increase the physical size of the transformer to obtain a desired performance with respect to phase angle errors. It is, therefore, desirable to provide a potential transformer of the type described for use with low power factor burdens, including means for reducing phase angle errors without increasing the physical size and weight of the transformer.

It is, therefore, an object of this invention to provide a new and improved potential transformer.

Another object of this invention is to provide a new and improved potential transformer including compensating means for reducing the phase angle error between the transformer primary and secondary voltages.

A further object of this invention is to provide a compensating means for potential transformers which will limit the phase angle error between the transformer primary and secondary voltages to a predetermined value for low power factor burdens.

A still further object of this invention is to provide a new and improved potential transformer having a phase angle error less than a predetermined value for a particular range of low power factor burdens and being physically smaller and lighter.

Other objects of the invention will, in part, be obvious and will, in part, appear hereinafter.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawing, in which:

FIGURE 1 is a view partly in side elevation and partly in section of a potential transformer embodying the teachings of this invention;

FIG. 2 is a fragmentary view of the potential transformer shown in FIG. 1 with the end section of the core removed;

FIG. 3 is an equivalent schematic diagram of the potential transformer shown in FIG. 1 when there is no load on the secondary winding of the transformer;

FIG. 4 is a vector diagram of currents and voltages of the equivalent circuit shown in FIG. 3;

FIG. 5 is an equivalent schematic diagram of the potential transformer shown in FIG. 1 when the secondary winding of the transformer is connected to a burden having a low power factor; and

FIG. 6 is a vector diagram of the voltages and currents of the equivalent schematic diagram shown in FIG. 5.

Referring now to the drawings and FIGS. 1 and 2 in particular, there is illustrated a potential transformer **10** embodying the teachings of this invention. The potential transformer **10** comprises a magnetic core **20**, which is

illustrated as being of laminated construction, a primary winding **40** which is disposed in inductive relationship with the magnetic core **20**, a secondary winding **50** which is also disposed in inductive relationship with the magnetic core **20** adjacent to the primary winding **40** and the close-circuited compensating windings **22** and **24** which are disposed in inductive relationship with the primary winding **40** and the secondary winding **50**. The insulation **32**, which may be of any suitable type, is disposed around the primary winding **40** and the secondary winding **50**. The compensating windings **22** and **24** are, therefore, insulated from the primary winding **40** and the secondary winding **50**.

Referring to FIG. 2, the compensating winding **22** is illustrated as being a short-circuited turn disposed about the secondary winding **50**. A potential transformer embodying the teachings of this invention may include one or more compensating windings similar to the compensating windings **22** and **24**. It is to be understood that a closed-circuited compensating winding could be employed including a particular impedance connected in circuit relationship with said compensating winding for certain applications. The compensating windings **22** and **24**, as illustrated, have a dominantly or highly resistive impedance characteristic for reasons which will be explained hereinafter. In other words, the voltage induced in the compensating windings **22** and **24**, when the primary winding **40** is connected to a source of voltage, (not shown) causes a current to flow in the compensating windings **22** and **24** which is substantially in phase with the induced voltage. The compensating windings **22** and **24** are provided in order to produce a current in the primary winding **40** which is substantially in phase with whatever voltage is impressed across the primary winding **40** of the transformer **10**.

Referring to FIGS. 3 and 4, the operation of the potential transformer **10** will be considered first when no load or burden is connected to the secondary winding **50**. Referring to FIG. 3 in particular, the terminals **12** and **14** represent the input terminals of the potential transformer **10** which are connected to the primary winding **40**. R_H and X_H represent the resistance and the reactance, respectively, of the primary winding **40** of the potential transformer **10**. R_T and X_T represent the resistance and the reactance, respectively, of the compensating windings **22** and **24** of the potential transformer **10**. The terminals **26** and **28** represent the output terminals of the compensating windings **22** and **24**, which in this case are effectively short-circuited. The voltage E_P represents the voltage at the input terminals **12** and **14** of the primary winding **40** when the potential transformer **10** is connected to a source of voltage (not shown). The terminals **42** and **44** represent the output terminals of the potential transformer **10** when no load or burden is connected across the secondary winding **50**. The current I_T represents the current produced in the primary winding **40** by the compensating windings **22** and **24** when no load or burden is connected to the secondary winding **50**. The voltage E_{SNL} represents the output voltage across the secondary winding **50** of the potential transformer **10** when no load or burden is connected to the secondary winding **50**. As illustrated in FIG. 4, the voltage E_{SNL} is the vector difference between the voltage E_P at the input terminals of the primary winding **40** and the voltage drop across the resistance R_H and the reactance X_H of the primary winding **40** due to the current I_T which is the current produced in the primary winding **40** by the compensating windings **22** and **24**.

Since the compensating windings **22** and **24** each have a dominantly resistive impedance characteristic which is relatively large compared to the reactances X_H and X_T of the primary winding **40** and the compensating wind-

ings 22 and 24, respectively, the current I_T is substantially in phase with the voltage, E_P, at the input terminals 12 and 14 of the primary winding 40. Therefore, the voltage drop produced by the current I_T across the reactance X_H of the primary winding 40 is substantially in quadrature or 90° out of phase with the voltage E_P at the input terminals 12 and 14, as shown in FIG. 4. The voltage drop produced by the current I_T across the resistance R_H of the primary winding 40 is substantially in phase with the voltage, E_P, at the input terminals 12 and 14 of the primary winding 40. The voltage drop produced across the entire impedance of the primary winding 40 is represented by the vector I_TZ_H. In summary, the effect of the compensating windings 22 and 24 is to introduce a phase angle difference or shift γ between the voltage, E_P, at the input terminals 12 and 14 of the primary winding 40 and the voltage E_{SNL} across the secondary winding 50 which appears at the terminals 42 and 44 of the equivalent circuit in FIG. 3 when the secondary winding 50 is not connected to a load or burden. The phase angle shift or correction γ between the voltage, E_P, and the voltage, E_{SNL}, across the secondary winding 50 when no load or burden is connected thereto, is conventionally regarded as a negative phase angle shift or correction since the secondary voltage, E_{SNL}, lags the primary voltage, E_P, in time phase. It is to be understood that the voltage drops I_TX_H and I_TR_H, as well as the phase angle γ, are exaggerated in the vector diagram shown in FIG. 4, in order to clarify the explanation of the operation of the potential transformer 10 when no load or burden is connected to the secondary winding 50.

Referring to FIGS. 5 and 6, the operation of the potential transformer 10 will be considered for the normal case where a burden 60 is shown connected to the output terminals 100 and 102 of the secondary winding 50. R_S and X_S represent the resistance and the reactance, respectively, of the secondary winding 50 in the equivalent circuit shown in FIG. 5. The equivalent circuit shown in FIG. 5 is similar to the equivalent circuit shown in FIG. 3 except that the equivalent circuit shown in FIG. 5 illustrates the case when the secondary winding 50 is connected to a load or burden 60. The current I_S represents the current which flows in the primary winding 40 when a burden 60 having a low power factor is connected to the terminals 100 and 102 of the secondary winding 50. The total current, I_P, in the primary winding 40 is the vector sum of the current, I_T, produced by the compensating windings 22 and 24 in the primary winding 40 and the current, I_S, which is the current produced in the primary winding 40 when a burden 60 is connected to the terminals 100 and 102.

Referring now to FIG. 6 in particular, the vector voltage, E_S, represents the output voltage of the potential transformer 10 across the secondary winding 40 at the terminals 100 and 102 when a burden 60 having a low power factor is connected to the terminals 100 and 102. The voltage, E_S, is the vector difference between the voltage E_{SNL} which would appear at the terminals 100 and 102, as well as the terminals 42 and 44, when no burden or load is connected to the terminals 100 and 102, and the voltage drops across the reactances X_H and X_S of the primary winding 40 and the secondary winding 50, respectively, and the voltage drops across the resistances R_H and R_S of the primary winding 40 and the secondary winding 50, respectively, due to the current I_S which flows when a burden 60 having a low power factor is connected to the terminals 100 and 102. It is clear that for a particular burden having a low power factor, as illustrated in FIG. 6, the voltage, E_S, will be substantially in phase with the voltage, E_P, applied at the input terminals 12 and 14 of the primary winding 40 and that the phase angle error between the primary and secondary voltages of the transformer 10 will be substantially eliminated for that particular burden having a low power factor. It has also been found that the phase angle error is reduced

below a predetermined value for a particular range of burdens having a low power factor due to the effect of the compensating windings 22 and 24. It should be noted that the phase angle shift or correction γ produced by the compensating windings 22 and 24 between the voltage, E_P, across the primary winding 40 and the voltage, E_{SNL}, which is the voltage across the secondary winding 50 when no load or burden is connected to the terminals 100 and 102, remains the same regardless of the magnitude or power factor of the burden 60 connected to the terminals 100 and 102. The compensating windings 22 and 24 also produce a change in the effective ratio of the potential transformer 10 which may be compensated for by a change in the actual turns ratio between the primary winding 40 and the secondary winding 50 of the potential transformer 10. It should be noted that in the vector diagrams the turns ratio of the transformer 10 is assumed to be 1:1 in order to permit greater clarity of representation. It will be recognized that this is the equivalent of letting the vectors represent volts per turn instead of total voltage.

The effect on the operation of the potential transformer 10 of the compensating windings 22 and 24 can be more clearly understood by considering the operation of the transformer 10 in the absence of the compensating windings 22 and 24. Referring to the vector diagram shown in FIG. 6, there would be substantially no phase angle shift or correction γ in the absence of the compensating windings 22 and 24. Therefore, the voltage, E_S, across the secondary winding at the terminals 100 and 102 would be the vector difference between the voltage, E_P, at the input terminals 12 and 14 of the transformer 10 and the voltage drops across the resistance, R_H, and the reactance, X_H, of the primary winding 40 and the voltage drops across the resistance, R_S, and the reactance X_S, of the secondary winding 50 produced by the current I_S which flows when a burden 60 having a low power factor is connected to the terminals 100 and 102 of the secondary winding 50. It will be readily appreciated that the phase angle between the voltage, E_S, at the terminals 100 and 102 will then be out of phase with the voltage, E_P, at the input terminals 12 and 14 of the transformer 10 by a phase angle error which is conventionally regarded as positive.

In summary, the compensating windings 22 and 24 operate to produce a voltage drop I_TX_H across the reactance X_H of the primary winding 40 which is substantially equal and opposite or 180° out of phase with the voltage drop produced across the through resistance of the transformer 10, which includes the resistances, R_H, and, R_S, of the primary winding 40 and the secondary winding 50, respectively, by the current, I_S, which flows to the burden 60 having a low power factor for a particular value of the burden 60. For a particular range of variation of the burden 60 having a low power factor, the phase angle error between the primary voltage, E_P, and the secondary voltage, E_S, of the transformer 10 will be reduced or substantially eliminated.

In order to obtain a particular phase angle shift or correction γ between the primary voltage, E_P, and the secondary voltage, E_{SNL}, when no load or burden is connected to the terminals 100 and 102, it is obvious that the current, I_T, may be varied by varying the resistance of the compensating windings 22 and 24 or by varying the reactance, X_H, of the primary winding 40 by conventional methods such as varying the relative spacing between the primary winding 40, the secondary winding 50 and the compensating windings 22 and 24. In order to obtain a higher value for the reactance X_H, the primary winding 40 and the secondary winding 50 should preferably be of the type known to the art as pancake coils. In addition, the reactance X_H can be increased by loosely coupling magnetically the primary winding 40 to the secondary winding 50 and by loosely coupling magnetically the primary winding 40 to the compensating wind-

ings 22 and 24. The reactance X_H can also be increased by closely coupling magnetically the compensating windings 22 and 24 to the secondary winding 50.

It is to be understood that a closed short-circuited compensating winding similar to the compensating windings 22 and 24 could be provided for a potential transformer in a particular application with suitable impedance connected across the compensating winding in order to obtain a desired value for the phase angle shift or correction γ between the primary and secondary voltages of a potential transformer when no load or burden is connected to the secondary winding of the transformer.

The apparatus embodying the teachings of this invention has several advantages. A potential transformer, including means for compensating for phase angle error when a burden having a low power factor is connected to the secondary winding of the transformer, would be physically smaller in size and lighter in weight than a conventional potential transformer which reduces the phase angle error by increasing the physical size of the potential transformer in order to reduce or substantially eliminate phase angle errors for particular burdens having a low power factor. In addition, the means disclosed for compensating for phase angle error in a potential transformer is relatively simple and convenient in its application and manufacture or assembly.

Since numerous changes may be made in the above-described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all the matter contained in the foregoing description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

We claim as our invention:

1. A potential transformer comprising a magnetic core, a primary winding disposed on said core and adapted for connection across a source of voltage, a secondary winding disposed on said core and connected to a burden having a low power factor, said primary winding and said secondary winding being disposed in side by side relation and displaced from one another on said core, and a short-circuited compensating winding disposed on said core for producing in said primary winding a component of current substantially in phase with the voltage from said source to compensate for phase angle error between the primary and secondary voltages of said transformer due to the flow of the low power factor current of said secondary winding through the effective resistances of said primary and secondary windings, the impedance of said compensating winding being dominantly resistive.

2. A potential transformer comprising a magnetic core, a primary winding disposed in inductive relationship with said core, a secondary winding disposed in side by side relation with said primary winding along a common axis and in inductive relationship with said core and primary winding, and a close-circuited compensating winding having a highly resistive impedance characteristic disposed in inductive relationship with said primary winding and core for producing in said primary winding a current which is substantially in phase with the voltage across said primary winding to compensate for phase angle error between the primary and secondary voltages of said transformer, the current which flows in said compensating winding producing a phase angle shift between the voltage input applied across said primary winding and the voltage across said secondary winding which is substantially equal and opposite to the phase angle shift between said voltages produced by the current which flows in said primary winding for a predetermined burden connected to said secondary winding having a low power factor.

3. Means for compensating for the phase angle error between the primary and secondary voltages in a potential transformer having a magnetic core on which are disposed in side by side relation and spaced apart from one another a primary winding adapted for connection across a source of voltage and a secondary winding adapted for connection to a low power factor burden comprising a close-circuited compensating winding disposed around said secondary winding in inductive relationship with said primary and secondary windings for producing in said primary winding a current which is substantially in phase with said voltage of said source across said primary winding to thereby limit the phase angle error between the primary and secondary voltages of said transformer to a predetermined value for a predetermined range of values of said burden.

4. A potential transformer comprising a magnetic core, a primary winding disposed on said core and adapted for connection across a source of voltage, a secondary winding disposed on said core and adapted for connection to a low power factor burden, said primary winding and said secondary winding being disposed in side by side relation and displaced from one another along a portion of said core, and a compensating winding comprising a short-circuited turn having a dominantly resistive impedance disposed in inductive relationship with said primary and secondary windings for producing in said primary winding a current substantially in phase with the voltage of said source across said primary winding, the current produced in said primary winding by said turn producing a voltage drop across the reactance of said primary winding which is substantially equal and 180° out of phase with the voltage drop across the through resistance of said transformer produced by the current flow to a predetermined burden when connected to said secondary winding to thereby compensate for the phase angle error between the primary and secondary voltages of said transformer.

5. A potential transformer comprsing a magnetic core, a primary winding disposed in inductive relationship with said core and adapted for connection across a source of voltage, a secondary winding disposed in inductive relationship with said core and adapted for connection to a burden having a low power factor, said primary winding and said secondary winding being disposed in side by side relation and displaced from one another along a portion of said core, said secondary winding being loosely coupled magnetically with said primary winding, and a close-circuited compensating winding disposed in inductive relationship with said primary and secondary windings for producing a current in said primary winding which is substantially in phase with the voltage of said source across said primary winding to compensate for the phase angle error between the primary and secondary windings of said transformer.

6. A potential transformer adapted for connection across a source of voltage comprising a magnetic core, a primary winding disposed about said core and adapted for connection across said source of voltage, a secondary winding disposed on said core adjacent to said primary winding and adapted for connection to a low power factor burden, said primary winding and said secondary winding being disposed in side by side relation along a common axis on said core and displaced from one another, and a close-circuited compensating winding having a dominantly resistive impedance characteristic disposed about said secondary winding in concentric relation with said secondary winding and said core adjacent to said primary winding for producing in said primary winding a current substantially in phase with the voltage of said source across said primary winding, the current produced in said primary winding by said compensating winding resulting in a voltage drop across the reactance of said primary winding which is substantially equal and opposite in phase to the voltage drop across the through resistance of said transformer produced by the current flow to a predetermined burden when connected to said secondary winding to thereby compensate for the phase angle error between the primary and secondary voltages of said transformer.

7. A potential transformer adapted for connection across a source of voltage comprising a magnetic core, a primary winding disposed in inductive relation with said core and adapted for connection across said source of voltage, a secondary winding disposed in inductive relation with said core in side by side relation with said primary winding and adapted for connection to a low power factor burden, said secondary winding being loosely coupled magnetically with said primary winding, and a close-circuited compensating winding disposed in inductive relation with said primary and secondary windings for producing a current in said primary winding which is substantially in phase with the voltage of said source across said primary winding to compensate for phase angle error between the primary and secondary voltages of said transformer, said compensating winding being loosely coupled magnetically with said primary winding and closely coupled magnetically with said secondary winding, said compensating winding having a dominantly resistive impedance characteristic.

8. A potential transformer adapted for connection across a source of voltage comprising a magnetic core, a primary winding disposed on said core and adapted for connection across said source of voltage, a secondary winding disposed on said core and adapted for connection to a burden having a low power factor, said primary winding and said secondary winding being generally hollow cylindrical in configuration and disposed in side by side spaced relation with one another along a common axis, a short-circuited compensating winding disposed on said core around said secondary winding for producing in said primary winding a component of current substantially in phase with said voltage from said source across said primary winding to compensate for phase angle error between the primary and secondary voltages of said transformer, the voltage drop produced by the latter current component across the effective reactance of said primary winding being substantially 180° out of phase with the voltage drop produced across the through resistance of said transformer due to the current in said secondary winding, the impedance of said compensating winding being dominantly resistive, and being relatively large compared to the equivalent reactances of said primary winding and said compensating winding.

9. In combination, a source of voltage, a potential transformer including a magnetic core, a primary winding associated with said core and adapted for connection across a source of voltage and a secondary winding associated with said core and adapted to apply a measure of said voltage to a burden having a low power factor, said

primary winding and said secondary winding being disposed in side by side relation along a common axis and axially displaced from one another, a compensating winding comprising a short-circuited turn disposed in inductive relationship with said core and in concentric relation with said secondary winding for producing in said primary winding a current which is substantially in phase with said voltage across said primary winding to compensate for phase angle error between the primary and secondary voltages of said transformer, the voltage drop produced by the latter current component across the effective reactance of said primary winding being substantially 180° out of phase with the voltage drop produced across the through resistance of said transformer due to the current in said secondary winding, the impedance characteristic of said turn being dominantly resistive, and being relatively large compared to the equivalent reactances of said primary winding and said turn.

10. A potential transformer adapted for connection across a source of voltage comprising a magnetic core, a primary winding disposed in inductive relation with said core and connected across said source of voltage, a secondary winding disposed in inductive relation with said core in side by side relation with said primary winding and connected to a low power factor burden, said secondary winding being loosely coupled magnetically with said primary winding, and a close-circuited compensating winding disposed in inductive relation with said primary and secondary windings for producing a current in said primary winding which is substantially in phase with the voltage of said source across said primary winding to compensate for phase angle error between the primary and secondary voltages of said transformer, the voltage drop produced by the latter current component across the effective reactance of said primary winding being substantially 180° out of phase with the voltage drop produced across the through resistance of said transformer due to the current in said secondary winding, said compensating winding being loosely coupled magnetically with said primary winding and having a dominantly resistive impedance characteristic which is relatively large compared to the equivalent reactances of said primary winding and said compensating winding.

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