May 29, 1934. H. P. MILLER, JR 1,960,415

CONTROL ELEMENT FOR CAPACITIVE CURRENTS

Filed March 11, 1932 3 Sheets-Sheet 1

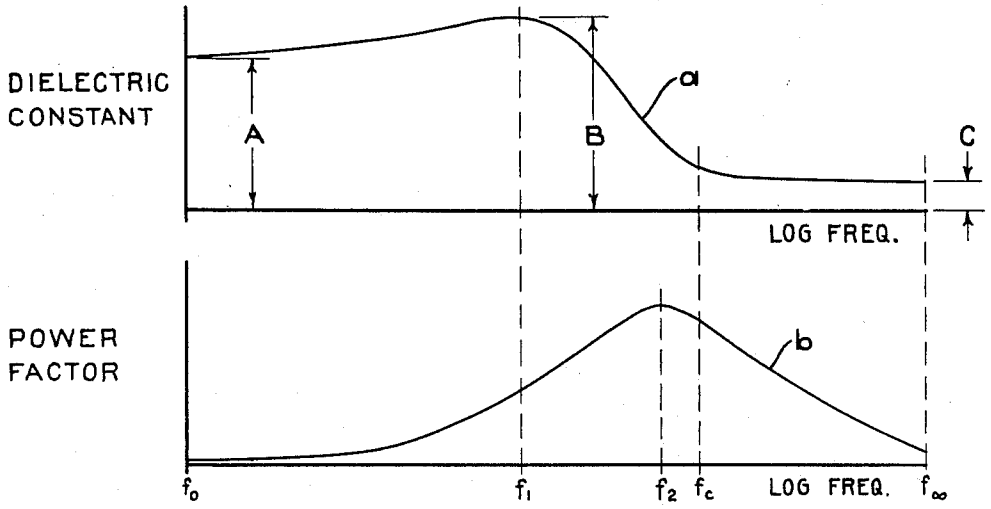


FIG. 1

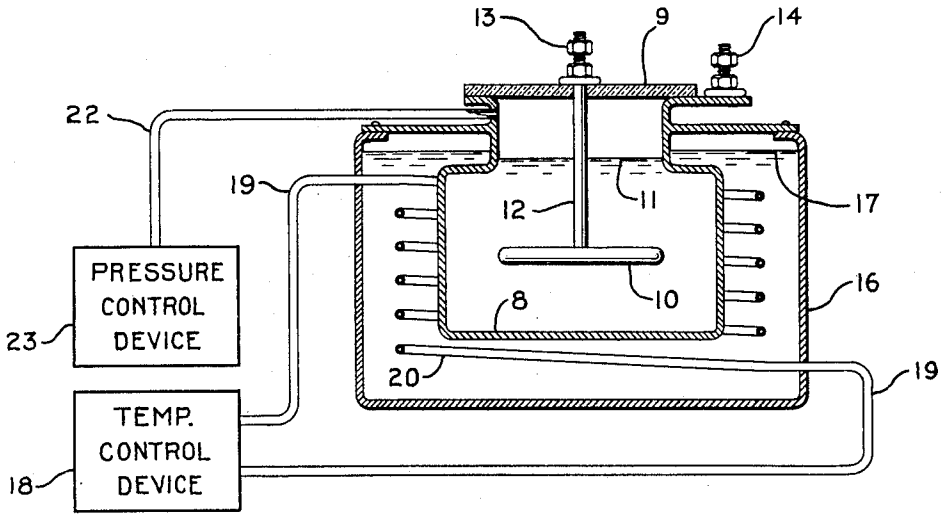


FIG. 2

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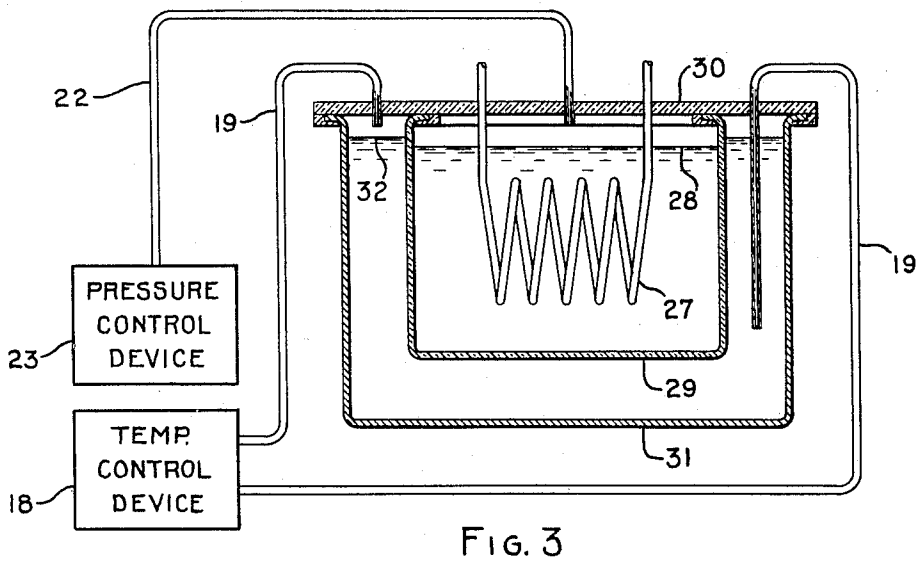


FIG. 3

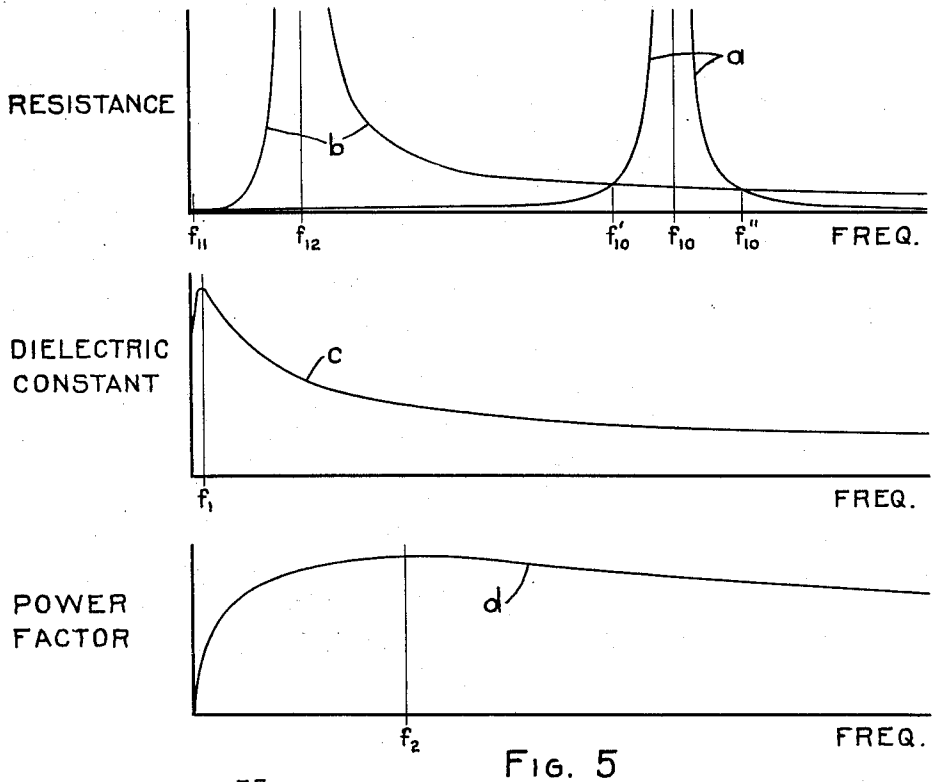


FIG. 5

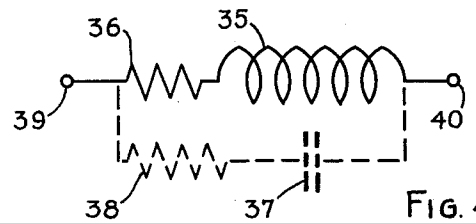


FIG. 4

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CONTROL ELEMENT FOR CAPACITIVE CURRENTS

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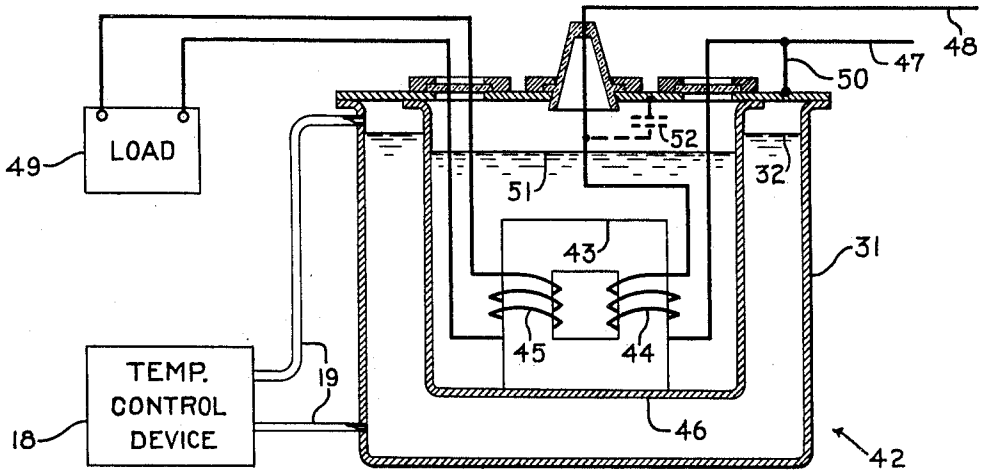


FIG. 6

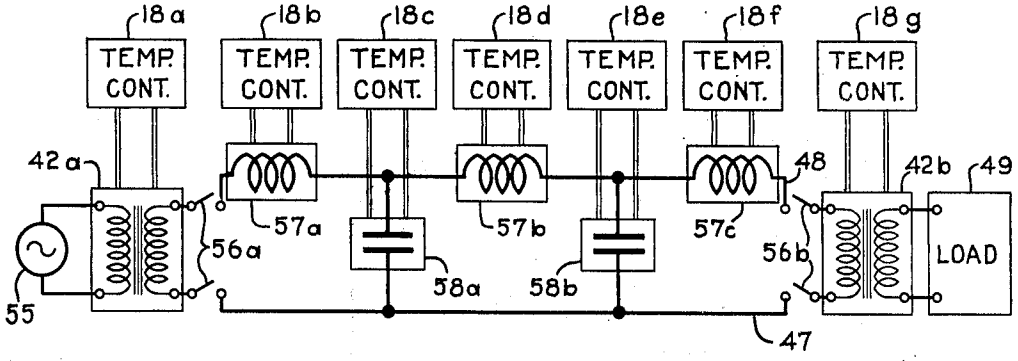


FIG. 7

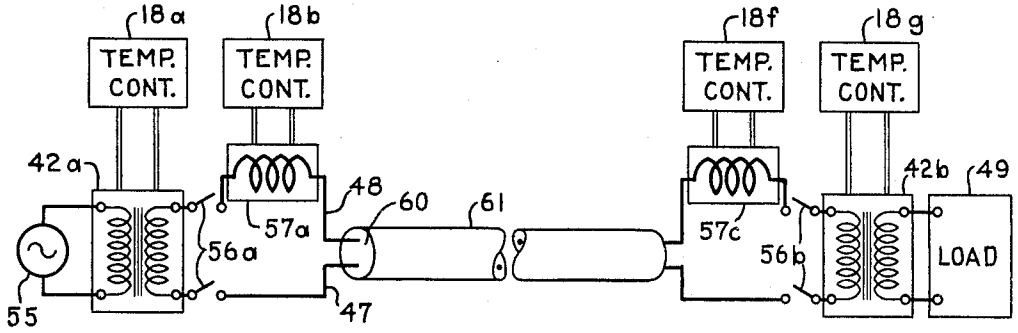


FIG. 8

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UNITED STATES PATENT OFFICE

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CONTROL ELEMENT FOR CAPACITIVE CURRENTS

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Application March 11, 1932, Serial No. 598,233

23 Claims. (Cl. 171—97)

This invention relates to a method of and means for employing dielectric mediums to control electric currents and more particularly for employing dielectric mediums whose impedance characteristics are adjustable.

Distributed capacitance occurs in many elements of electrical systems due to the proximity of conductors with alternating potentials of opposite polarities. The dielectrics in such capacitances are often of such low loss as to offer little impedance to harmonic, parasitic, or transient wave frequencies impressed on the conductors. This may give rise to abnormal voltages which endanger insulation in the system or cause interference to other electrical systems. Attempts have been made to control the effects of such undesired frequencies by the use of absorbing circuits, reactors, resistors, or electrostatic shields. These have not been entirely effective and in some cases have resulted in the loss of power at the normal frequency as well as at the undesired frequencies. In the present invention there are associated with the distributed capacitances dielectric mediums whose losses are low at the normal frequency but may be high at the undesired frequencies and may be adjusted to desired values at these frequencies by methods described hereinafter.

It is an object of this invention to employ the dielectric medium of a condenser for characterizing the impedance of an electrical system.

Another object of this invention is to provide a dielectric medium for the electrostatic field of capacity forming elements which will cause the impedance between such elements to vary with the frequency of the field in a manner which may be prearranged.

Another object of this invention is to vary the phase and amplitude of currents at one or more frequencies in an electrical circuit by treating the dielectric medium of a condenser associated with that circuit.

A further object of this invention is to provide in an electrical system an improved method of and means for attenuating the currents of one or more frequencies and wave form without decreasing the efficiency of the system at other frequencies.

A still further object of this invention is to employ a condenser for coupling two or more electrical circuits and to control the characteristics of such coupling through treatment of the dielectric medium in the condenser.

The novel features that I consider characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of certain specific embodiments, when read in connection with the accompanying drawings in which like reference characters represent like elements and in which:

Fig. 1 shows curves illustrating the manner in which the properties of dielectric mediums employed in this invention vary with the logarithm of the frequency.

Fig. 2 is a vertical section of a condenser employing the principles of this invention.

Fig. 3 is a vertical section illustrating a method for treating the electrostatic field of an inductor, Fig. 4 represents diagrammatically the reactances and resistances of such an inductor, while Fig. 5 shows the manner in which certain properties of this inductor vary with the frequency.

Fig. 6 is a vertical section of a transformer employing the principles of this invention in the distributed capacitances of its windings.

Fig. 7 shows diagrammatically a power transmission system employing a number of elements utilizing this invention, while Fig. 8 shows a similar system in which the transmission conductors are in the form of a sheathed cable.

In this invention use is made of a so-called "polar" dielectric whose dielectric constant increases with the frequency over one frequency range and decreases with the frequency over another. Such a dielectric is said to have "normal" dispersion when the dielectric constant increases with frequency and "anomalous" dispersion when it decreases with frequency. Most dielectrics have marked normal dispersion but only the polar dielectrics have been found to have both normal and anomalous disperson. In polar dielectrics high values of dielectric loss and power factor are also obtained at or near a particular frequency called the "characteristic" frequency. These properties have been observed in polar dielectrics including gases, such as ammonia and sulfur dioxide; liquids, such as water, alcohol, castor oil and glycerine; and solids, such as ice and rosin. Each medium has a characteristic frequency of its own some of which are known in the art, the range of such frequencies being approximately from zero to 5×10^{10} cycles per second and possibly higher.

Fig. 1 shows the approximate manner in which the dielectric properties of a liquid having anom-

alous dispersion vary with the logarithm of the frequency, curve *a* being the dielectric constant and curve *b* the power factor. In curve *a* for the range of normal dispersion the dielectric constant rises from a value A at a low frequency f_0 to a value B at a frequency f_1. In the range of anomalous dispersion it drops from the value B to a value C at a very high frequency $f\infty$. The power factor, curve *b*, starts with a low value at f_0, rises to a peak value at a frequency f_2 and returns to a low value at $f\infty$. The characteristic frequency f^c is higher than either f_1 or f_2 and may be approximately determined by the following equation:

$$f_c=\frac{T}{\eta}K$$

where T is the absolute temperature, η is the coefficient of viscosity, and K is a constant depending on the size of the molecules in the dielectric used. The relative position of f_c with reference to f_1 and f_2 for a given medium remains the same when f_c is changed so that increasing T or decreasing η will increase f_1 and f_2 as well as f_c.

To obtain a desired power loss in a condenser at a given frequency a dielectric medium may be selected whose value of f_2 under normal conditions of temperature T and viscosity η is the same as the given frequency and whose power factor at f_2 is higher than necessary to produce the desired loss. Adjustment to the proper loss may then be made by raising or lowering the temperature T. The temperature and viscosity are in many cases interdependent so that an increase in temperature causes a decrease in viscosity. For this reason when starting with f_2 at the given frequency a slight increase in temperature will shift f_2 to a much higher frequency and cause a very large decrease in the loss, while a corresponding decrease in temperature will shift f_2 to only a slightly lower frequency and cause very little decrease in the loss. Referring to curve *a* it is seen that these changes in loss will be accompanied by changes in dielectric constant. Increasing the temperature will increase the dielectric constant up to the value B and then decrease it to the value A. Decreasing the temperature will decrease the dielectric constant to the value C. It has been found that the effect of decreasing the viscosity may be obtained without changing the temperature by diluting the medium with a less viscous medium. If the diluting medium also has the properties of anomalous dispersion, two characteristic frequencies will be obtained and hence a high power factor will occur over two different frequency bands. If the diluting medium does not have these properties, its effect will be simply that of decreasing the viscosity. In many dielectrics benzene and carbon tetrachloride may be used for diluting purposes. In the case of gaseous dielectrics the viscosity may be changed by adjusting the gas pressure.

Fig. 2 shows a form of condenser which may be used to select or employ dielectric mediums in accordance with the principles of this invention. In this drawing a metal container 8 of any suitable conducting material, such as iron or copper, has mounted on its top opening an insulating plate 9 of suitable material and dielectric strength. The plate 9 is attached to the container 8 in a manner to maintain the desired conditions of temperature and pressure within the container. Inside of the container 8 and suitably spaced with reference to its sides is a metal condenser plate 10 shaped in a manner to equalize the electrostatic stress in a dielectric medium 11 placed between the plate 10 and the container 8. The medium 11 may be a gas, a liquid, or a solid having the properties of anomalous dispersion as enumerated above; a combination of two or more substances having these properties; or a combination of one or more of such substances with one or more substances not having the properties of anomalous dispersion. The plate 10 is supported by a suitable conducting rod 12 which may be fastened to the insulating plate 9 and which has on its upper end a suitable connection terminal 13. Another connection terminal 14 may be attached to the container 8. Surrounding the container 8 and connected to it in a manner to form an enclosing jacket is another container 16 of metal, wood, or a suitable heat insulating material. The jacket between containers 8 and 16 may be filled with a gaseous, liquid, or a solid medium 17 capable of storing heat and maintaining the temperature of the dielectric medium 11 at the desired value. The temperature of the medium 17 may be maintained at the desired value by means of a temperature control device 18 acting through connecting tubes 19 and a circulating coil 20 in the well known manner. The control device 18 may include any suitable refrigeration or heating system well known in the art with thermostatic control. The pressure of the dielectric medium 11 may be maintained at any value, such as that required to obtain the desired characteristic frequency f_c, through a connecting tube 22 by means of a pressure control device 23. This device 23 may be a vacuum or pressure pump with an automatic pressure regulator.

It is to be understood that the principles of the condenser of Fig. 2 may be applied to other forms of condensers, such as variable tuning condensers, multiple plate fixed condensers, and condensers formed by conductors in close proximity to each other. A dielectric medium of power factor and dielectric constant to meet specified operating conditions at a given temperature may be selected for any such form of condenser in the manner outlined above. I have found, for example, that a condenser containing a commercial grade of castor oil at a temperature of 70 degrees Fahrenheit when inserted in the radio frequency circuit of an oscillator would not permit oscillations at 45×10^6 cycles per second. Diluting the castor oil with carbon tetrachloride made oscillations possible due to the shift of the frequency f_2 to a higher value. With a solution of 90% castor oil and 10% carbon tetrachloride by weight oscillations were obtained at this frequency and temperature. Raising the temperature of the mixture to 95 degrees Fahrenheit caused the power factor to decrease by at least 3%.

Fig. 3 shows the manner in which the principles of this invention may be applied to the distributed capacitance of an inductor consisting of a spiral winding 27 constructed in such a manner as to give the desired inductance, resistance, and distributed capacitance. Surrounding this winding, or associated with it in a way to influence its electrostatic field, is a dielectric medium 28 which may be similar to and have the same properties as the dielectric medium 11 in Fig. 2. The medium 28 may be enclosed in a container 29 of a suitable material, such as glass, quartz, or copper, and constructed in such a manner as to have negligible effect on the electrostatic and magnetic fields of the winding 27. An insulating plate 30 of

suitable material and dielectric strength may be attached to an opening in the container 29 in a manner to maintain desired conditions of temperature and pressure within the container. Surrounding the container 29 and attached to the plate 30 is a container 31 containing a medium 32, preferably a poor electrical conductor, such as water or Transil oil, which is capable of storing heat and maintaining the temperature of the medium 28 at the desired value. The temperature of the medium 32 and the pressure of the medium 28 may be maintained at desired values by control devices 18 and 23 similar to those in Fig. 2.

Figs. 4 and 5 illustrate the effect of a dielectric medium having anomalous dispersion on the effective resistance of an inductor, such as winding 27 in Fig. 3. It is well known that the electrical characteristics of a winding of this type may be represented diagrammatically as in Fig. 4 in which inductor 35 and resistor 36 represent the inductance and resistance respectively of the winding, and condenser 37 and resistor 38 the distributed capacitance and its dielectric resistance. The effective resistance of this combination to a potential applied across terminals 39 and 40 when the dielectric medium is air will vary with the frequency approximately in the manner shown in curve *a* of Fig. 5. In this curve frequency f_{10} represents the resonant frequency of the inductor 35 and the condenser 37. Suppose now that the winding is surrounded with a dielectric medium whose dielectric constant and power factor vary in the manner shown in curves *a* and *b* of Fig. 1 and the corresponding curves *c* and *d* of Fig. 5. Due to the greater dielectric constant of the medium, the condenser 37 will have a higher capacitance and the resonant frequency of the winding will be shifted to a lower frequency f_{12}. The effective resistance of the winding will then vary approximately as shown in curve *b* of Fig. 5. It is seen that the resistance at frequency f_{11} is the same for both curves *a* and *b* but that curve *b* has a broader peak and does not decrease as rapidly at the higher frequencies. This effect is due mainly to the shapes of the dielectric constant and power factor curves. It is only at frequencies between f'_{10} and f''_{10} that curve *a* has higher values than curve *b*. Considerable adjustment of resistance values over particular frequency ranges may be obtained by selection of the dielectric medium and the adjustment of its temperature. It is also possible to combine the effects of windings whose peak frequencies f_{12} have widely different values.

A winding having the resistance characteristics of curve *b* in Fig. 5 may be advantageously employed in a conductor carrying current at a very low frequency, such as 60 cycles per second. At this frequency its impedance would be low, but at high frequencies both its resistance and reactance would be high. If the reactance happened to be tuned out at certain high frequencies by reactance of opposite sign in the conductor or its terminal equipment, the resistance would still be high enough to attenuate voltages at these frequencies. Using a winding having a resistance curve as in *a* of Fig. 5, only frequencies in the neighborhood of f_{10} would be attenuated. At other frequencies the resistance would be low and the winding might resonate with the conductor and terminal equipment thus helping to increase the amplitude of undesired high frequency voltages.

Fig. 6 shows the manner in which the principles illustrated in Figs. 4 and 5 may be applied to the protection of the windings of a transformer 42. This transformer may be of a form well known in the art, such as the shell type employed on frequencies in the neighborhood of 60 cycles per second, and consist of a steel core 43 on which are positioned a primary winding 44 and a secondary winding 45. The core 43 rests on and is in electrical contact with a steel shell 46. Connections from the windings 44 and 45 may be made to transmission line conductors 47 and 48 and to a suitable load 49. Conductor 47 may be connected to the shell 46 through a suitable jumper 50. Instead of using a medium such as Transil oil for cooling the core 43 and windings 44 and 45, a dielectric medium 51 having the properties of anomalous dispersion, as described hereinabove, may be employed. The temperature of the dielectric medium 51 may be maintained at a desired value in the same manner as in Fig. 3 by a container 31, medium 32, temperature control device 18 and connecting tubes 19. The effective distributed capacitance from the high potential conductor 48 and the winding 44 to the shell 46 may be represented schematically by a condenser 52.

The winding 44 of transformer 42 may be subject to the effect of voltages of high frequency and steep wave front impressed on the conductors 47 and 48 by methods enumerated hereinafter. These voltages may be high enough to damage the insulation on winding 44 or to induce sufficient voltage into the winding 45 to damage insulation in that winding and in the load 49. By the use of a dielectric medium 51 having the properties of anomalous dispersion, the capacitance of condenser 52 is made large so that it effectively shunts the winding 44 and attenuates the high frequency voltages. This reduces the dangerous voltages impressed on the windings 44 and 45 and the load 49 and thus eliminates possible short circuits and insulation breakdowns.

Referring now to Fig. 7 there is shown a complete system for transmitting power from an alternating current generating source 55 to a load 49 and employing many embodiments of my invention. The source 55 and load 49 may be connected to the transmission line conductors 47 and 48 through suitable switches 56*a* and 56*b* and transformers 42*a* and 42*b* of the type shown in Fig. 6. In the conductor 48 may be inserted choke coils 57*a*, 57*b*, and 57*c* of the form shown in Fig. 3. Between the conductors 47 and 48 at points subject to undesired high voltages may be positioned condensers 58*a* and 58*b* of the form shown in Fig. 2. Each of the elements employing the principles of this invention may be provided with a suitable control such as a temperature control device 18*a*, 18*b*, 18*c*, . . . , and 18*g*. Pressure control devices as shown in Figs. 2 and 3 have been omitted from Figs. 7 and 8 for the purpose of simplifying the drawings. These elements may be adjusted to cooperate with each other in providing the desired impedance characteristics in different parts of the system. While a single phase transmission system has been shown for purposes of illustration, it is to be understood that these elements may be similarly applied to polyphase systems.

It is well known in the art that in addition to the fundamental and harmonic voltages from the source 55 destructive voltages of high frequency and steep wave front may be impressed on the system of Fig. 7 by surges due to opening or closing of the switches 56*a* and 56*b*; by lightning strokes to the conductors 47 and 48 or objects as-

sociated therewith; by short circuiting arcs between lines 47 and 48 or between elements of opposite polarity in the system; or through coupling with adjacent transmission systems. Due to the flexibility provided in employing the principles of this invention, the impedance characteristics of the system may be adjusted so as to effectively attenuate all such disturbances to a harmless point without affecting its operation at the desired frequencies. Since these disturbances are generally momentary in character and would cause little heating of the dielectrics, the operating temperatures of the elements may be constant enough to permit the elimination of the temperature control devices 18*a*, 18*b*, 18*c*, . . . , and 18*g*.

Fig. 8 shows a similar transmission system in which a part of the transmission conductors 47 and 48 are embedded in a dielectric medium 60 and surrounded by a metallic casing 61. The dielectric medium 60 may have the properties of anomalous dispersion and be selected in the manner described hereinabove to give the desired transmission characteristics at the average operating temperature of the cable. In this way undesired voltages of high frequency and steep wave front may be attenuated in the cable, the system thereby having an intrinsic damping action.

In general the principles of my invention permit imparting to many forms of condensers a wide variety of impedance characteristics. These characteristics may be accurately adjusted for particular operating frequencies. They permit the adjustment of distributed capacitance in a manner that is not possible with ordinary condensers and if this adjustment is made over wide enough limits the loss characteristics need not be changed. They also permit the introduction of resistance into distributed capacitance in a more effective and efficient manner than is possible with ordinary resistors. Finally they provide reactance elements of predetermined impedance characteristics which may be employed in series with other elements for attenuation purposes or in parallel with other elements for by-pass or coupling purposes.

Many modifications of my improved control elements for capacitive currents will be apparent to those skilled in the art and my invention, therefore, is not to be restricted to the specific embodiments chosen for purposes of illustration, but is to be limited only by the scope of the appended claims.

What I claim is:

1. In combination, a reactance element having a plurality of capacitance forming surfaces integral therewith, means for generating and impressing alternating potentials of different frequencies on said element, a dielectric medium having the properties of anomalous dispersion associated with said surfaces, and means for controlling the impedance of said element to the currents resulting from said potentials, said means causing a change in the dielectric properties of said medium.

2. In combination, a transmission line, a reactance element therein, a plurality of capacitance forming surfaces integral with said element, and a plurality of dielectric mediums having the properties of anomalous dispersion associated with said surfaces, said mediums imparting a prearranged impedance characteristic to said element.

3. In combination, a transmission line, a reactance element in said line, a dielectric medium associated with said element having the properties of anomalous dispersion, means for influencing said medium with transmitted vibrations at a plurality of frequencies over said line, and a source of heat vibrations at a definite frequency for impressing on and influencing said medium, said source causing amplitude changes in said first vibrations which are greater over a particular band of said frequencies than over other bands.

4. In combination, a transmission line, an inductive winding located therein having distributed capacitance, and a dielectric medium having the properties of anomalous dispersion associated with said winding causing a prearranged impedance characteristic in said winding.

5. In combination, a transmission line, an inductive winding located therein having distributed capacitance, and a plurality of dielectric mediums at least one of which has the properties of anomalous dispersion associated with said winding, said mediums causing prearranged impedance characteristics in said winding.

6. In combination, a transmission system, an inductive winding therein having distributed capacitance, a dielectric medium having the properties of anomalous dispersion associated with said winding, and means cooperating with said medium for controlling the impedance characteristics of said winding.

7. In combination, a transmission system, an inductive winding therein having distributed capacitance, a dielectric medium having the properties of anomalous dispersion associated with said winding, and a temperature control device for changing the impedance characteristics of said winding.

8. In combination, an inductive winding having distributed capacitance, means for impressing a plurality of alternating potentials of different frequencies on said winding, a dielectric medium having the properties of anomalous dispersion cooperating with said winding for attenuating the currents resulting from said potentials of at least one of said frequencies, and means for controlling the pressure on said medium.

9. In an electrical system, a transmission line, a plurality of reactance elements located therein employing dielectric mediums having the properties of anomalous dispersion, and means for causing said mediums to provide a prearranged impedance characteristic for said line.

10. In a transmission system, an alternating current energy source, a load circuit for said source, a transmission circuit connecting said source with said load circuit, means for changing the frequency of at least a portion of the energy from said source, and means for attenuating at least a portion of the currents resulting from said energy of changed frequency without changing the alternating currents from said source, said attenuating means comprising reactance elements employing dielectric mediums having the properties of anomalous dispersion.

11. In combination, a source of alternating current, a load circuit, and an impedance element for coupling said source to said load circuit, said element employing a dielectric medium having the properties of anomalous dispersion.

12. In combination, a source of alternating current, a load circuit, an impedance element for coupling said source to said load circuit and employing a dielectric medium having the properties of anomalous dispersion, and means for changing the dielectric properties of said medium, said change in dielectric properties causing a change in said coupling.

13. In combination, a transmission system, an inductive winding therein having distributed capacitance, a plurality of dielectric mediums at least one of which has the properties of anomalous dispersion associated with said winding, and means cooperating with said mediums for controlling the impedance characteristics of said winding.

14. In combination, a transmission system, an inductive winding therein having distributed capacitance, a dielectric medium having the properties of anomalous dispersion associated with said winding, and a pressure control device for changing the impedance characteristics of said winding.

15. In combination, an inductive winding having distributed capacitance, means for impressing a plurality of alternating potentials of different frequencies on said winding, a dielectric medium having the properties of anomalous dispersion associated with said winding causing attenuation of the currents resulting from the potentials of at least one of said frequencies, and means cooperating with said medium for changing the attenuation of said currents.

16. In combination, an inductive winding having distributed capacitance, means for impressing a plurality of alternating potentials of different frequencies on said winding, a dielectric medium having the properties of anomalous dispersion associated with said winding causing attenuation of the currents resulting from the potentials of at least one of said frequencies, and means comprising temperature control of said medium for changing the attenuation of said currents.

17. In a transmission system, an alternating current energy source, a load circuit for said source, a transmission circuit connecting said source with said load circuit, means for changing the frequency of at least a portion of the energy from said source, means comprising reactance elements employing dielectric mediums having the properties of anomalous dispersion for attenuating the alternating currents resulting from said energy of at least one of said changed frequencies to a greater degree than the alternating currents from said source, and means cooperating with said mediums for changing the attenuation of at least one of said alternating currents.

18. In combination, a source of alternating currents of a plurality of frequencies, circuits containing a plurality of paths for said currents connected to said source, a plurality of reactance elements located in said paths, and a dielectric medium having the properties of anamolous dispersion associated with at least one of said elements for preventing said currents of at least one of said frequencies from traversing at least one of said paths.

19. In combination, a source of alternating currents of a plurality of frequencies, circuits containing a plurality of paths for said currents connected to said source, inductance elements having distributed capacitance located in at least one of said paths, and a dielectric medium having the properties of anomalous dispersion associated with at least one of said inductance elements for introducing appreciable losses into at least one of said paths for at least one of said frequencies.

20. In combination, a source of alternating currents of a plurality of frequencies, circuits containing a plurality of paths for said currents connected to said source, a plurality of reactance elements located in said paths, a dielectric medium having the properties of anomalous dispersion associated with at least one of said elements for attenuating currents of at least one of said frequencies, and means cooperating with said medium for controlling said attenuation in at least one of said paths.

21. In combination, interconnected circuits forming a plurality of paths for electrical currents of different frequencies, a plurality of reactance elements located in said paths, and a dielectric medium having the properties of anomalous dispersion associated with at least one of said elements for attenuating currents of at least one of said frequencies.

22. In combination, a source of alternating current, a load circuit, an impedance element for coupling said source to said load circuit and employing a dielectric medium having the properties of anomalous dispersion, and means comprising temperature control of said medium for causing a change in said coupling.

23. In combination, a source of alternating current, a load circuit, an impedance element for coupling said source to said load circuit and employing a dielectric medium having the properties of anomalous dispersion, and means comprising pressure control of said medium for causing a change in said coupling.

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