May 13, 1941. H. W. WAHLQUIST 2,241,831

POWER SYSTEM AND SHUNT FOR REDUCING HARMONICS THEREIN

Filed March 20, 1940 3 Sheets-Sheet 1

Fig. 1.

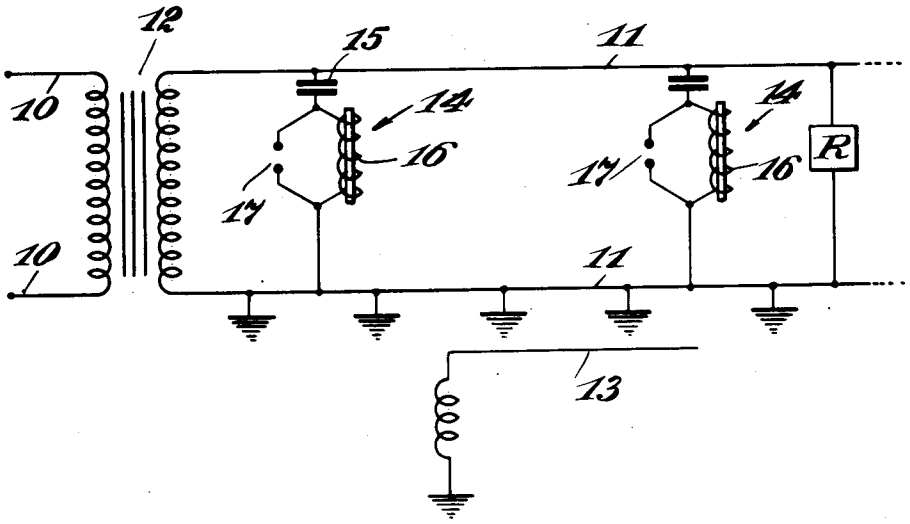
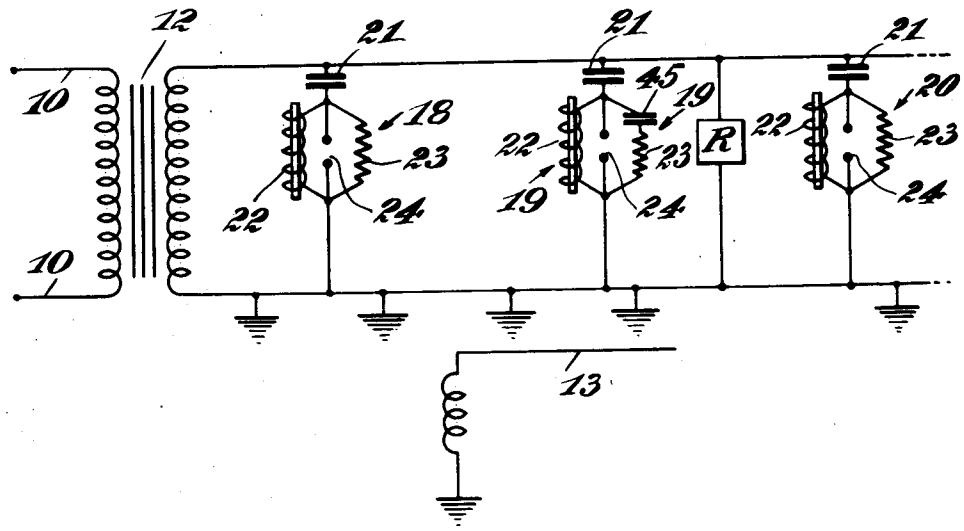


Fig. 2.



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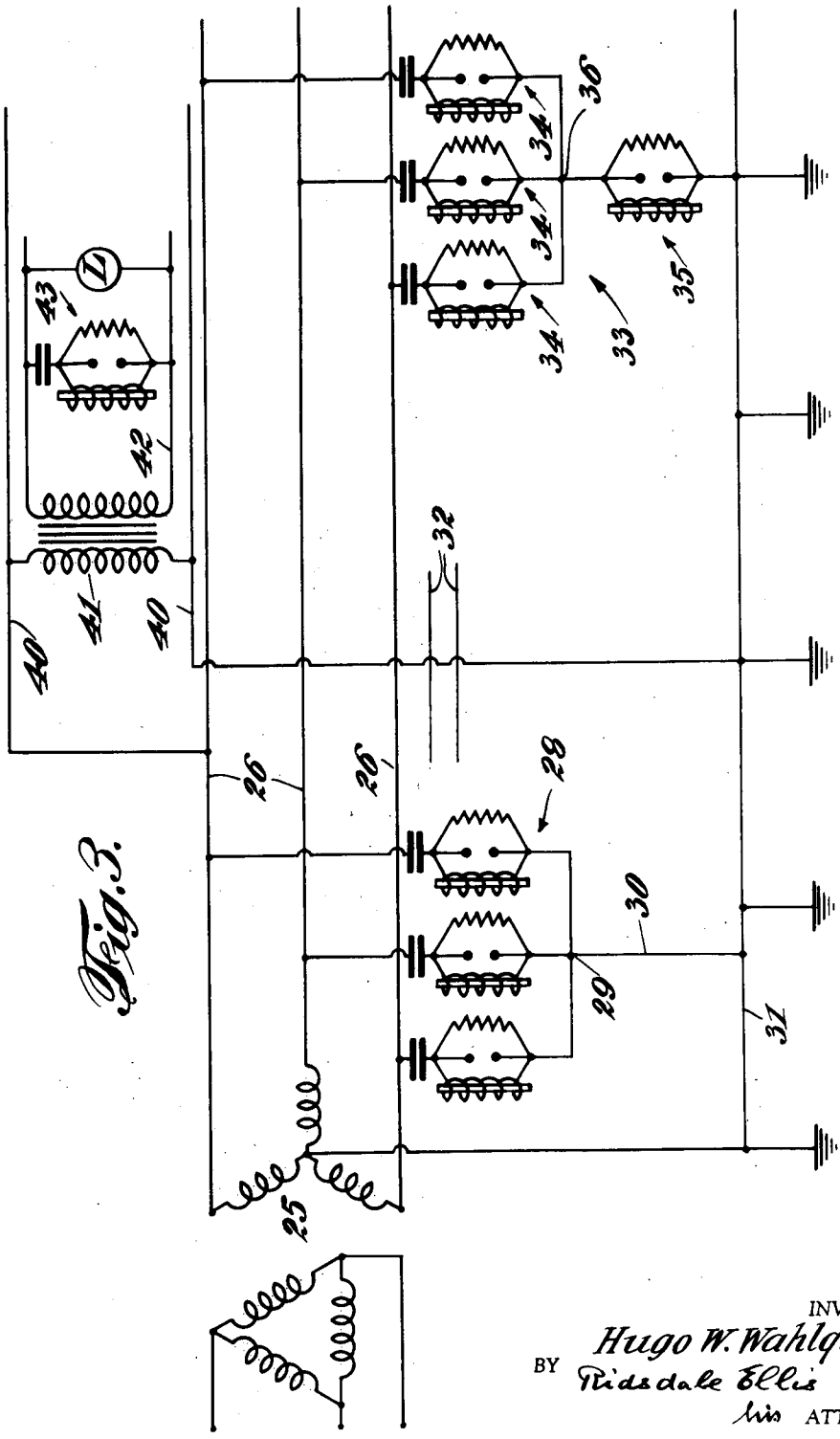


Fig. 3.

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POWER SYSTEM AND SHUNT FOR REDUCING HARMONICS THEREIN

Filed March 20, 1940 3 Sheets-Sheet 3

Fig. 4.

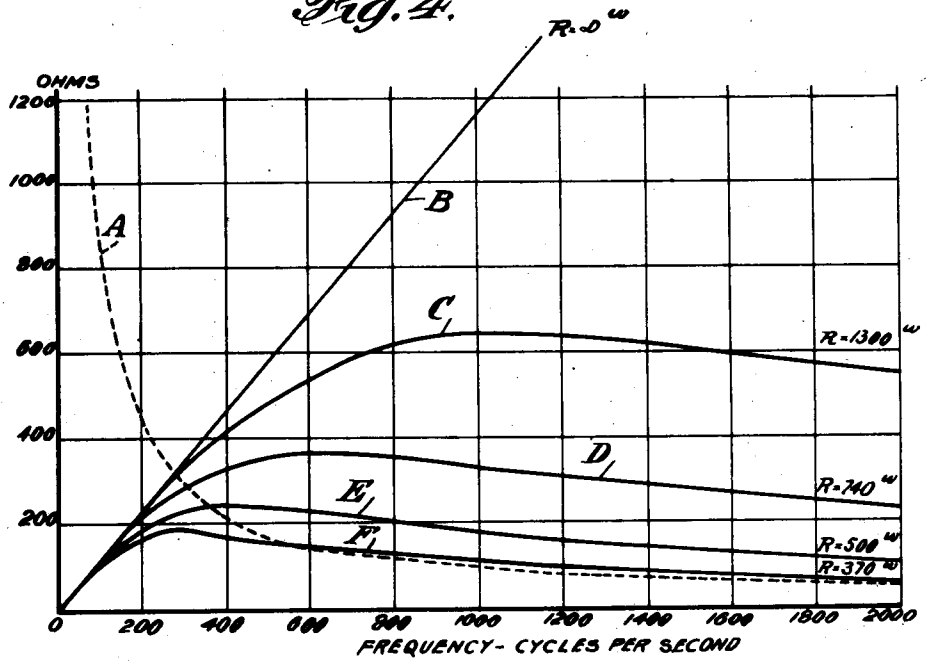
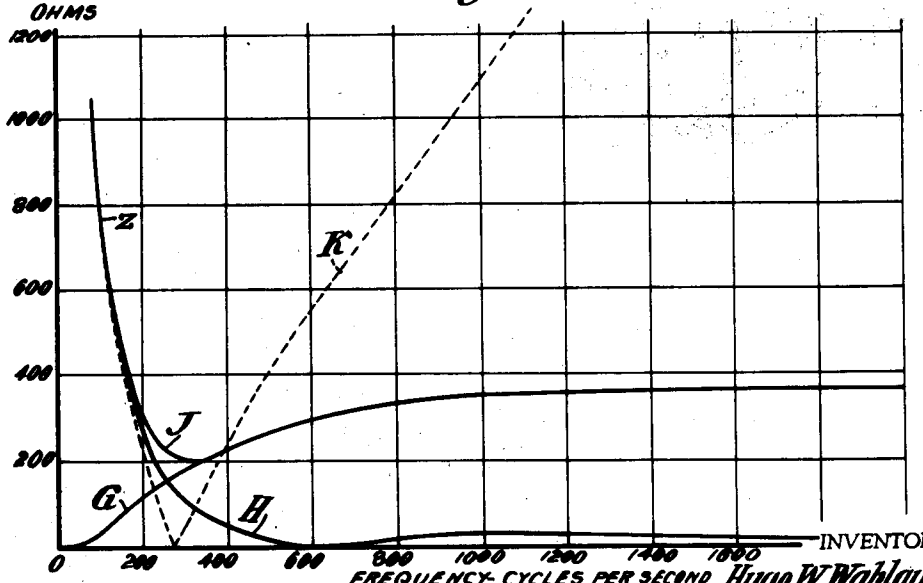


Fig. 5.



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Patented May 13, 1941 2,241,831

UNITED STATES PATENT OFFICE

2,241,831

POWER SYSTEM AND SHUNT FOR REDUCING HARMONICS THEREIN

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Application March 20, 1940, Serial No. 324,940

20 Claims. (Cl. 171—97)

This invention relates to power systems and shunts for reducing harmonics therein. Although not restricted thereto, the invention is particularly applicable to power lines having considerable distributed capacitance fed by supply systems having considerable inductance, such lines having, by virtue of such capacitance and inductance, a normal resonance at a frequency in the voice frequency range and especially between 500 and 2,000 cycles. Further, while the most frequent reason for using such shunts is to prevent interference with paralleling telephone or other communication lines, such shunts are often desirable to improve the power transmission efficiency of power lines. Large amounts of harmonics may create serious fluctuations in the voltage, noise in radio sets connected to the line, increased losses, and other objectionable effects.

This application is a continuation-in-part of Patent No. 2,212,963, issued August 27, 1940.

For many power systems, whether of the above specific type or not, it is advantageous to use a shunt comprising an inductance element in series with a capacitor. However, as the impedance of the ordinary inductance element increases proportionately to the frequency, it follows that such a series shunt offers high reactance to the flow of high frequency current. Consequently, while the shunt may prevent resonance between the line and the supply system at some frequency over 500 and may act as a short circuit for currents of the particular frequency at which the shunt itself is resonant, it may not to any great extent by-pass other high-frequency current originating in either the supply system or the loads thereon.

One of the objects of the invention is to provide an improved form of shunt or network of shunts which destroy resonance in both the balanced and residual circuits at any frequency, whereby the necessity for elaborate and careful investigation of the line characteristics is avoided.

Further, line characteristics change from time to time as the result of line extensions and connected load. Such changes also change the resonant frequencies so that a device is required which will destroy resonance irrespective of frequency.

Another general object of the invention is to provide an inductive element, the inductance of which does not increase proportionately with frequency. Such an inductive element reduces the reactance of the shunt for frequencies above that at which the shunt itself is resonant, and makes the shunt act more nearly like a resistance above the resonant frequency.

Such a variable inductance may be constructed by using a high-loss iron core or by placing a resistance in parallel with an air-core coil, or by a combination of both methods, i. e., an iron-core coil with a resistance in parallel therewith, or by short-circuited turns using an air core, or by short-circuiting the turns through a resistance, if an iron core is used. Shunts of the above type may be used to advantage with rectifiers and other loads creating large amounts of harmonics. Usually the volume of harmonics created by such load is so large that a single simple capacitor shunt cannot reduce them sufficiently to give good telephone service in nearby lines. The above-mentioned variable inductance shunts are, however, so much more efficient that they can be used in many cases where otherwise a plurality of tuned shunts would have to be employed. When used to reduce harmonics created by one particular load, such as a large rectifier, it is desirable to place the shunt adjacent the load. However, the harmonics generated by the usual loads, such as those arising from transformer exciting currents from transformers distributed along the line, can be taken care of by my improved shunt substantially irrespective of the location of the shunt, where resonance occurs in the voice frequency range between the supply system inductance and the line capacitance.

The chief specific object of the invention is to extend this principle to the point at which the reactance of the inductive element actually decreases with frequency above, say, 500 cycles at about the same rate as the reactance of a capacitor decreases with frequency. By proper selection of the constants of the capacitor and of the inductive element, the two reactances may be made substantially equal and so cancel each other over a wide range of frequencies in the usual voice range. The shunt over such range acts substantially like a pure resistance.

Another specific object is to provide a substantially non-resonant shunt which at the fundamental frequency, usually 60 cycles, acts as if it were substantially a pure capacitance, while from, say, 300 cycles upwards, it acts as if it were substantially pure resistance, the value of which can be predetermined. Such a shunt has a number of important applications.

It can be used to terminate a line with a shunt which at frequencies well above the fundamental frequency acts like a relatively low resistance

and thus prevents the building up of harmonic currents due to reflection. Reflection is strongest when the load on the line is weakest and is substantially absent when the balanced and residual circuits are terminated by a resistance equal to the respective characteristic balanced and residual impedances of the line. The characteristic impedance of a power line is represented approximately by $\sqrt{L/C}$, L and C being the inductance and capacitance constants of the line per unit of length. For an average overhead single-phase line this is in the order of 500 ohms. For an average three-phase line it is in the order of 300 ohms.

Such a shunt acts as a wattless load at the fundamental frequency, but as a resistance load at the harmonic frequencies. It is not always necessary to place it at the end of or adjacent the end of the line. It may often be used to advantage near the middle of the line, especially when the telephone exposure is near the end of the power line.

The above form of shunt is also useful as a means for reducing the flow of harmonics from the supply source, whether they originate in the generator or supply transformer. In fact, the best arrangement is where one non-resonant shunt is placed across the line adjacent the supply transformer and the other is used to terminate the line.

The preferred form of shunt forming the subject-matter of the present invention consists of two parts in series with each other. The first is a capacitor which offers very considerable impedance to 60-cycle current. The second consists of a reactor and a resistor in parallel, the constants of which are chosen so that at 60-cycle current the impedance of the reactor is considerably less than that of the resistor. As a result the greater part of the 60-cycle current which the capacitor permits to flow goes through the reactor. As the current through the capacitor and reactor is wattless, it follows that little of the 60-cycle current passing through the shunt is expended in useless generation of heat.

Various suitable applications of the invention are illustrated diagrammatically, by way of example, in the accompanying drawings, wherein:

Fig. 1 illustrates a single-phase power system paralleling a telephone line and embodying the present invention;

Fig. 2 illustrates a single-phase power system embodying a non-resonant shunt constructed in accordance with the present invention;

Fig. 3 illustrates a three-phase power system with shunts similar to those shown in Fig. 2;

Fig. 4 is a graph showing various reactance-frequency relationships; and

Fig. 5 is a graph showing further reactance-frequency relationships.

As shown in Fig. 1, **10** represents a power line supplying energy to a second multigrounded single-phase power line **11** by a transformer **12**. A telephone line running parallel to and in close proximity to the power line **11** is indicated by **13**. Across the line **11**, preferably before it comes near the telephone line, is connected a shunt designated generally as **14** for reducing the higher harmonic currents in the line **11** beyond its point of connection. If a resonant condition exists between the supply system inductance and the line capacitance, harmonics in the vicinity of the resonance point and originating either in the supply system, load transformers, or loads will be increased by such resonance. The shunt **14** adjacent the supply system will destroy this resonance condition, thereby reducing the harmonics, from both the supply system and loads.

However, when the line **11** is near or above one-quarter wave length at important frequencies, it may be necessary to place a second shunt toward the far end of the line to prevent the build-up of harmonics from resonance in the line itself. This second shunt would be especially important if a harmonic generating load such as a rectifier R were out on the line. The second shunt **14**, placed adjacent the rectifier, will act as an additional preventative to the flow of harmonics back toward the first shunt as well as outwards toward the open end of the line.

Each shunt comprises a capacitor **15** and a reactor **16** in series therewith. The reactor **16** is provided with an iron core constructed so that it has relatively high eddy current losses at frequencies in the usual voice range. With an iron core having thick laminations, the reactance of the coil does not increase nearly as rapidly with frequency as would be the case if such iron core or its equivalent were not used.

As a capacitor acts as a short-circuit for lightning discharges, while an inductance blocks them due to the very high frequency (steep wave front) of such discharges, a gap shunt **17** is, to advantage, connected around the reactor to by-pass such discharges. Since the 60-cycle voltage across the reactor is relatively small, there is no tendency for power follow-up after the gap breaks down from surges.

The power system and shunt arrangement of Fig. 2 is broadly similar to Fig. 1, but the shunts **18**, **19**, and **20** are markedly different in that a resistor **23** is connected in parallel with the reactor **22** to enable the inductive reactance of the combination of resistor and reactor to decrease with frequency above, say, 500 cycles at about the same rate as the capacitance reactance of the capacitor **21**.

The shunts may have a condenser in series with the resistor, such as the condenser **45** of shunt **19**, to reduce the power loss at the fundamental frequency and lower the frequency at which the shunt as a whole acts substantially as if it consisted solely of the resistor.

To avoid making the insulation on the reactor unduly heavy, gap shunts **24** may be provided, as shown, to short-circuit lightning discharges.

While air-core inductance coils may be used when they are connected in parallel with a resistor, iron-core coils are ordinarily used as being cheaper. Since the circuit is essentially a high loss circuit at harmonic frequencies, the so-called "figure of merit" Q of the reactor can be small in comparison with the Q of reactors designed for conventional resonant shunts. Iron cores tend to generate harmonic currents, the greater the flux density the greater the volume of harmonics. Hence where reactors have been used previously, as in shunts tuned to one particular frequency, it has been customary to use air cores instead of iron cores. I have found that when a reactor and a resistor are used in parallel, the resistor very greatly reduces the volume of harmonics, so that the flux density may range between 30,000 and 50,000 or even 60,000 lines per square inch without causing trouble.

As shown, there are three such shunts, one **18** near the supply transformer to prevent harmonics generated in the supply system reaching that part of the line which parallels the telephone line, a second **19** to prevent harmonics generated

by a particular load, such as the rectifier R, and a third 20 acting as a line termination shunt to prevent the building up of harmonic currents due to reflection. In general, the use of any one of the shunts 18, 19, and 20 reduces the ground return harmonics in all parts of the line, so that all three are needed only in exceptionally bad situations. It is especially noteworthy that the shunt 19 will very greatly reduce the flow of harmonics from the rectifier R to the end of the line and that even if the shunt 18 is not used, the line terminating shunt 20 will largely prevent the rectifier R sending harmonics along the line toward the supply transformer 12 by destroying resonance.

Attention is also called to the fact that when a shunt is used at the supply end only on a very long line the harmonics originating in the loads may still give rise to important resonance effects. This resonance is prevented by the use of a terminating shunt toward the end of the line, although not necessarily at the precise end. Good results are often obtained where the shunt is half-way or two-thirds the way to the end.

Rural power systems frequently consist of a network of lines with numerous branches, and the impedance curve of the system is often complex due to secondary reflections from the branch lines. To prevent these reflections, the branch lines which are electrically long at harmonic frequencies may be terminated in addition to the main line termination. It is also possible to break up these reflection effects by a number of terminating networks distributed along the line, the individual networks having relatively high impedance (such as 1,000 or 2,000 ohms) compared with the characteristic impedance of the line. In the case of an electrically long single-phase branch from a three-phase four-wire system, a simple and inexpensive treatment would consist of a few low-voltage non-resonant shunts on the 110- or 220-volt windings of load transformers along the line at a spacing of, say, one 1 kv.-a shunt per mile. Fig. 3, shunt 43, illustrates this type of application.

In the case of a single-phase branch consisting of two phase wires from a three-phase system, a termination connected between the phase wires will not prevent resonance in the residual circuit. In a single-phase line of this type, a termination should be connected between each wire and ground. An alternative arrangement would consist of a three-phase termination or non-resonant shunt to ground on the three-phase line at or near the point where the single-phase branch connects to the three-phase line. This latter arrangement may be used to reduce the earth currents due to the unbalancing effect of a single-phase branch from three-phase lines of any type, i. e., delta, unigrounded, or multigrounded systems. In the case of the unigrounded system, the preferred arrangement would include a termination connected between the neutral wire and ground.

In the average three-phase rural power system the impedance of the three phases will differ due chiefly to differences in the lengths and locations of single-phase branches. Consequently, the resonance between the line capacitance and the supply system inductance will occur at a different frequency for each of the three phases. This results in relatively large residual currents in the three-phase section at the non-triple harmonic frequencies (5, 7, 11, etc. harmonics), which in a balanced system would have 120° phase relationship between phases and therefore cancel in the residual circuit. A non-resonant shunt connected to ground as in Fig. 3 and located either adjacent a high impedance supply system or at a considerable distance from the supply transformer, when the latter is very large, will be particularly effective in reducing the residual currents in both directions from the shunt, due to destruction of resonance in the residual circuit and to a balancing action tending to bring the non-triple components into 120° phase relationship. Similarly, a terminating network toward the end of a long line will tend to equalize the impedance of the three phases and be particularly effective in reducing residual components. This action is important because it is usually the residual current (or more specifically the current which appears as an earth-return current) that controls the overall influence of a power line on paralleling communication circuits.

The resonant frequency of the residual circuit of a power line will usually differ from the resonant frequency of the balanced circuit due to such factors as loads and Y-delta transformers with grounded neutral. The non-resonant shunts described in this application due to their non-selective characteristics are effective irrespective of the resonant frequencies.

Situations are sometimes encountered in which a pronounced condition of resonance exists in a long, high-voltage transmission line such as 60,000 or 110,000 volts. A terminating network placed directly on a line of such high voltage is expensive due to the high voltage rating required for the capacitors. Such lines generally supply large load centers through step-down transformers and in such cases the resonance in the high voltage line may be destroyed by connecting a non-resonant shunt across the low-voltage windings of one or more load transformers or the line adjacent thereto. This permits a cheaper installation since lower-voltage capacitors may be used.

Fig. 3 shows a series of Y-connected non-resonant grounded shunts of the type described in connection with Fig. 2, applied to a three-phase four-wire power line. Y-connected grounded shunts are usually preferable to either ungrounded Y-connected or delta-connected shunts because the former are capable of destroying resonance in the residual as well as the balanced circuits, while the latter do not destroy resonance in the residual circuits. A paralleling communication line is indicated diagrammatically at 32. In this case the three-phase conductors 26 are fed from a suitable delta-star transformer 25. A non-resonant shunt network 28 is connected between the conductors 26 and the neutral 27 adjacent the supply transformer.

This shunt network comprises three shunt units, each consisting of a capacitor, reactor and resistor, as in the case of the shunts 18, 19, and 20 of Fig. 2. One end of each shunt unit is connected to a common or neutral point 29 connected by a conductor 30 to the neutral 31.

Toward the open end of the line is a terminating shunt network 33 comprising three shunt units 34, each consisting of a capacitor, reactor and resistor. These units are connected together at 36 and this common or neutral terminal is connected through a unit 35, similar to 34 except that no capacitor is used, to the neutral 31, where, as shown, the neutral is multigrounded, to provide a ground connection.

The effect of the unit **35** is to shift the minimum point of the residual impedance of the network to a lower frequency than that of the units **34**. For example, if the units **34** are designed to have a minimum point at 300 cycles, the constants of the unit **35** may be chosen to give a minimum point at 180 cycles in the residual circuit. This would be advantageous, for example, where the magnitude of the 180-cycle component from transformer exciting currents was sufficiently great to require correction. In general, however, where the shunts **34** are designed for a minimum point as low as 300 cycles, the neutral element **35** is not required. The impedance of the shunt to residual components in such case will be one-third the impedance of unit **34**.

If it is desired to terminate both the balanced and residual circuits in substantially a pure resistance at harmonic frequencies and equal to the characteristic impedance of the line, the unit **35** should include a capacitor, and the constants chosen such that units **34** match the characteristic impedance of the balanced circuit of the line (usually around 350 ohms) and unit **35** in series with the parallel impedance of units **34** matches the characteristic impedance of the residual circuit of the line (usually around 250 ohms). This four-capacitor arrangement is, however, more expensive and a sufficiently close impedance match is obtained in practice with capacitors in units **34** only.

Connected to the power line is a single-phase extension **40** supplying power to the primary of a transformer **41**. The secondary of such transformer supplies power to a load L through line **42**. Across the line **42** is connected a non-resonant shunt **43** of the type above described. The shunt **43** prevents the extension line from acting as a capacitance when the load L is zero or very small and hence greatly reduces reflections, resonance and other injurious effects. The line **42** although short may, especially in conjunction with its feeder line **40**, be regarded as a power line.

The operation of the non-resonant shunts of Fig. 3 will be explained by assuming the following values for the constants of the shunt:

Capacitor__1.76 mfd. capacitance or C.
Reactor____185 milihenries inductance or L.
Resistor____370, 500, 740, 1300 and ∞ ohms resistance or R.

These constants are suitable for shunts for a three-phase 12 kv. power line using 6900-volt capacitors (voltage from line wires to neutral).

Curve A of Fig. 4 represents the variation in reactance with frequency of the above-mentioned capacitor. Curve B shows the same thing for the reactor, when R is ∞. Curve C shows the variation with frequency of the reactive component of the total impedance of the reactor and resistor combination when R is 1300 ohms. Curves D, E, and F show the corresponding relationships when R is 740, 500 and 370 ohms, respectively. It will be noted that, when R is 370 ohms, from 500 to 2,000 cycles and above, curves A and F almost coincide, i. e., the capacitive and inductive reactances of the shunt are substantially equal and, being 180° out of phase, neutralize each other.

The vector sum of the reactances indicated by the curves A and F is plotted in Fig. 5 as curve H. Curve G is the resistance component of the total impedance of the reactor and resistor combination when R is 370 ohms. The vector sum of the resistance curve G and the reactance curve H is plotted as curve J. It will be noted that the over-all impedance of the shunt has a minimum point of 210 ohms at around 300 cycles from which point it increases asymptotically towards 370 ohms.

While such a shunt as that just described has a minimum impedance point, the differences between the impedance at that point and at higher frequencies is so small compared with those obtained with straight capacitance and inductance shunts that this shunt may be termed a non-resonant shunt. To show how markedly differently my shunt operates from straight capacitance and inductance shunts, curve K has been added which represents the over-all reactance of a shunt having the same C and L, but having R=∞, i. e., when the shunt has only capacitance and inductance.

If it is desired to retain the minimum point at around 300 cycles, as shown in Fig. 5, but change R to some other value than 370, the requisite corresponding alterations in C and L can be computed from the following formulas:

$$R=2L$$
$$L=325/C$$

where

R=resistance of the resistance element in ohms
L=inductance of the reactor in milihenries
C=capitance of the capacitor in mfds.

If, instead of changing R, L, and C simultaneously, two only are changed, then the point at which the minimum point occurs and also the point at which the curves A and F substantially coincide will be changed.

Taking 300 cycles as *f*, then a minimum point at *af* cycles is obtained, with C fixed, by making the inductance

$$\frac{L}{a^2}$$

and the resistance

$$\frac{R}{a}$$

The following table gives the values of R and L for C fixed at 0.88 mfd.

R	L	C	Frequency of minimum point
1,480	1,480	0.88	150
1,100	840	0.88	200
740	370	0.88	300
370	92	0.88	600
222	33	0.88	1,000
148	15	0.88	1,500

It will be noted that the ratio of R to L changes from around 1:1 to 10:1 as the frequency of the minimum point goes up from 150 to 1500 cycles. A ratio of 1:1 in the balanced circuit results in substantial losses at 60 cycles and usually the ratio is around 2:1 or more. For the residual circuit lower ratios may be used as there is substantially no 60-cycle current to be contended with.

To change the relative values of C, L, and R for any desired minimum point, the first set of formulas is used. It will be noted, by applying the formulas to the figures given in the table, that for any fixed values of R and L, the value of C may be decreased by raising the frequency of the minimum point. Hence, from the point of view of cost alone, the higher the minimum

point the better. From the purely operative point of view, the reverse is usually true.

If a line-terminating shunt has a minimum point at a relatively high frequency, say 1,500, then resonance between the shunt on the one hand and the supply system and line between such system and the shunt on the other hand may occur at some frequency below 1,500 cycles. If such shunt were tuned with the supply system and intervening line to resonate at 250 cycles, then the 180- and 300-cycle current from the supply system would travel the entire length of the line. Also any 180- or 300-cycle currents generated by the loads on the line would be increased. Usually, however, the 180- and 300-cycle current is of negligible importance. Where the 180- and 300-cycle currents are of importance, R should equal 3L or less.

Even with the shunt near the supply system, it is advantageous to use one with a relatively low minimum point when there is a large amount of low harmonics as it reduces the flow of both low and high frequencies. Thus, with an abnormal amount of 300-cycle current, a shunt with a minimum point around 300 is advantageous although the cost is greater than for a shunt with a minimum of 600. If the low harmonics are not important, then a shunt with a high minimum point tuned with the supply system can be used, because, while the low harmonics may be increased, that increase often is of small consequence and the installation cost is reduced by cutting down the size of capacitor required. Where a shunt having a high minimum point, say 1,000 to 1,500 cycles, is located adjacent the supply system, the constants of the shunt should be such that the shunt resonates with the supply system at below 500 cycles, preferably at about 250.

In some cases, particularly where the line itself has considerable distributed capacity, it is desirable that the inductive reactance component of the line-terminating shunt be in excess of its capacitive reactance component. Such a condition would result from the constants represented by curves A and E, or in some instances A and D, of Fig. 4. In that case the distributed capacity of the line largely, if not wholly, cancels out the excess inductive reactance of the shunt. Such shunt is especially adapted for terminating a power line.

Where a terminating network is designed to match the characteristic impedance of the line and is located at the end of the line, the line impedance, as seen from the sending end, is practically a pure resistance. Where it is desired to terminate a line in its characteristic impedance, R should be around 500 ohms for single-phase and 300 ohms for three-phase lines. The chief advantage of such a shunt is that it can be applied to any power line irrespective of its length.

That does not mean, however, that in any particular case where the reduction of harmonics is the sole desideratum R may not vary widely from the figures above given. One function of the termination shunt is to introduce losses in the line at harmonic frequencies and thereby damp out resonance effects. This last statement applies also to shunts adjacent the supply system or between the ends of the power line.

A three-phase line termination shunt may be connected so as to terminate the line only as respects the residual circuit. In that case the phase reactors are omitted and the three capacitors are each connected at one end to each other and at the other end to one of the phase wires. The common or neutral terminal of the capacitors is connected through a reactor and resistor in parallel to ground.

This arrangement may be used where the resonance in the residual circuit only of the line is the important factor. This often occurs when the line is supplied by a direct-connected generator with its neutral grounded. With direct-connected generators, the triple harmonic frequencies are so outstanding that often they are all that have to be considered. To eliminate the effect of these triples, it is not essential to place a reactor-resistor combination in series with each of the three capacitors, one of such combinations in the line connecting the three capacitors to ground being sufficient. Usually an over-all impedance of 250 ohms is sufficient, considering the three capacitors as being in parallel and in series with the reactor-resistor combination.

I claim:

1. A power line system having a shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor and in series therewith an inductive element having a reactance which does not increase as rapidly as the frequency of the currents flowing therethrough in the usual voice frequency range.

2. A power line system having a shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor and in series therewith an inductance coil having an iron core having high eddy current losses in the usual voice frequency range.

3. A power line system having a shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor, a reactor in series therewith and a resistance, the reactor and resistance being connected in parallel with respect to each other.

4. In combination with a power line, a supply system therefor having inductance, and a shunt connected across the line to reduce the currents therein of higher frequency than the fundamental, such shunt including a capacitor and in series therewith an inductive element, the reactive component of which increases markedly less rapidly than the frequency of the currents flowing therethrough in the usual voice frequency range, the capacitive reactance of the shunt being equal to the combined inductances of the supply system and shunt at a frequency well below 500 cycles.

5. In combination with a power line, a supply system therefor having inductance, and a shunt connected across the line to reduce the currents therein of higher frequency than the fundamental, such shunt including a capacitor and in series therewith an inductive element, including an inductance coil and a resistance, the coil and resistance being connected in parallel with respect to each other, the capacitive reactance of the shunt being equal to the combined inductances of the supply system and shunt at a frequency well below 500 cycles.

6. A non-resonant shunt for reducing currents of higher frequency than the fundamental in power lines, comprising a capacitor and a reactor connected in series with each other, and a resistor connected in parallel with the reactor, the impedance of the three parts of the shunt being so proportioned to each other that over a wide range of frequencies the reactive component of the reactor and resistor combined is

of the same order of magnitude as the reactance of the capacitor.

7. In combination with a power line fed from a supply system by a transformer, a shunt connected across the power line adjacent the transformer, such shunt comprising a capacitor and a reactor connected in series with each other, and a resistor connected in parallel with the reactor, the impedance of the three parts of the shunt being so proportioned to each other that over a wide range of frequencies the reactive component of the reactor and resistor combined is of the same order of magnitude as the reactance of the capacitor.

8. A non-resonant shunt for preventing the building up of high frequency currents due to reflections in power lines comprising a capacitor and a reactor connected in series with each other, and a resistor connected in parallel with the reactor, the impedance of the shunt in the usual voice frequency range being about equal to the characteristic impedance of the power line.

9. In combination with a power line, a supply system therefor, a shunt connected across the power line adjacent its end farthest from the said supply system, said shunt comprising a capacitor, a reactor connected in series with the capacitor and a resistor connected in parallel with the reactor, the total impedance of the shunt in the usual voice frequency range being about equal to the characteristic impedance of the power line.

10. In combination with a power line system, a load thereon of a type creating harmonics and a communication line running parallel to the power line, a capacitive shunt having high capacity relative to inductance connected across the power line between the point of supply of power to the power line and a point not greatly beyond that at which the parallel relation between the two lines begins and a second capacitive shunt having high capacity relative to inductance connected across the power line between the harmonic-generating load and a point not beyond that at which such parallel relation ends, to reduce a plurality of the higher harmonics in that section of the power line system which runs parallel to the communication line.

11. In combination with a power line having considerable distributed capacitance fed by a supply system having a relatively high inductance and having, by virtue of such capacitance and inductance, a normal resonance at a frequency between 500 and 2,000 cycles, a shunt across the power line including both a capacitor and an inductive element having impedances such that the resonant frequency of the power line and supply system is reduced to below 500 cycles, the inductance element having a reactance which does not increase as rapidly as the frequency of the currents flowing therethrough to reduce the flow of currents of higher frequency than 500 cycles in the power line.

12. In combination with a power line having considerable distributed capacitance fed by a supply system having a relatively high inductance and having, by virtue of such capacitance and inductance, a normal resonance at a frequency between 500 and 2,000 cycles, a shunt across the power line, such shunt comprising a capacitor and a reactor connected in series with each other, and a resistor connected in parallel with the reactor, the impedance of the three parts of the shunt being so proportioned to each other that at around 500 to 1,000 cycles the reactive component of the reactor and resistor combined is of the same order of magnitude as the reactance of the capacitor, to destroy resonance above 500 cycles and to reduce the flow of currents of higher frequency than 500 cycles in the power line.

13. A three-phase power line system having a Y-connected shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor in each branch of the shunt and a connection between the neutral point of the shunt and the ground, said connection having in series therewith a reactor and resistor in parallel with each other.

14. A three-phase power line system having a Y-connected shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor and in series therewith a reactor and resistor in parallel with each other in each branch of the shunt and a connection between the neutral point of the shunt and the ground, said connection having in series therewith a reactor and resistor in parallel with each other.

15. A three-phase power line system having a Y-connected shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor and in series therewith a reactor and resistor in parallel with each other in each branch of the shunt and a connection between the neutral point of the shunt and the ground.

16. A three-phase power line system having a Y-connected shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor in each branch of the shunt and a connection between the neutral point of the shunt and the ground, said connection having in series therewith a reactor and resistor in parallel with each other.

17. A three-phase power line system having a Y-connected shunt across the power line for reducing currents therein of higher frequency than the fundamental, including a capacitor and in series therewith a reactor and resistor in parallel with each other in each branch of the shunt and a connection between the neutral point of the shunt and the ground said connection having in series therewith a reactor and resistor in parallel with each other, the resistance of each of the first three of said resistors in ohms being greater than the inductance of the corresponding reactor in millihenries.

18. An inductive unit for reducing currents in power lines of a frequency higher than the fundamental frequency having an effective inductive reactance which decreases as the frequency of the current flowing therethrough increases above a point in the lower part of the voice range, comprising a reactor and a resistor connected in parallel, the resistance of the resistor in ohms being under 1500 and also between 1.5L and 10L where L is the inductance of the reactor alone in millihenries.

19. In combination with a three-phase power line, a Y-connected shunt, each arm of which includes a capacitor, a reactor connected in series with the capacitor and a resistor connected in parallel with the reactor, the impedance of the three elements of each arm of the shunt being so proportioned to each other that over a wide range of frequencies the reactive component of the reactor and resistor combined is of the same

order of magnitude as the reactance of the capacitor, and a connection from the neutral point of the Y-shunt to ground including a resistor and reactor in parallel with each other, the impedance of the entire combination from the three lines to ground over a wide range of frequencies being substantially resistance, the capacitive and inductive components substantially neutralizing each other over such range.

20. In combination with a three-phase power line, a Y-connected, capacitive shunt and a connection from the neutral point of the Y-shunt to ground including a resistor and a reactor in parallel with each other, the impedance of the entire combination from the three lines to ground over a wide range of frequencies being substantially resistance, the capacitive and inductive components substantially neutralizing each other over such range.

HUGO W. WAHLQUIST.