Nov. 7, 1939. C. P. STOCKER 2,179,386

FREQUENCY CHANGING SYSTEM

Filed May 2, 1938 2 Sheets-Sheet 1

Fig. 1.

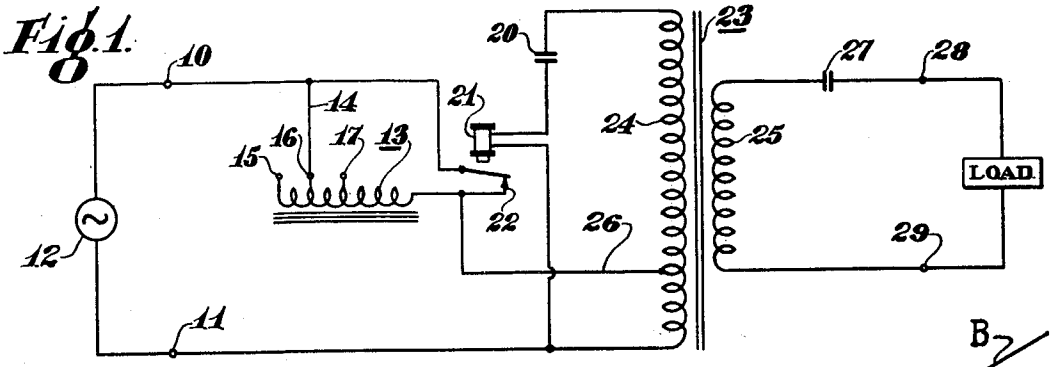


Fig. 2.

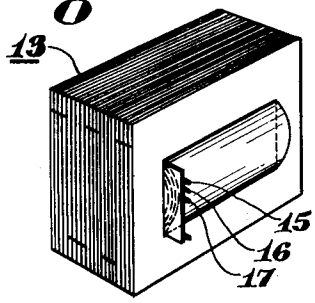


Fig. 3

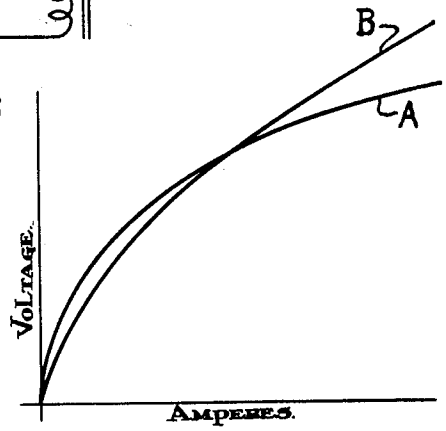


Fig. 4.

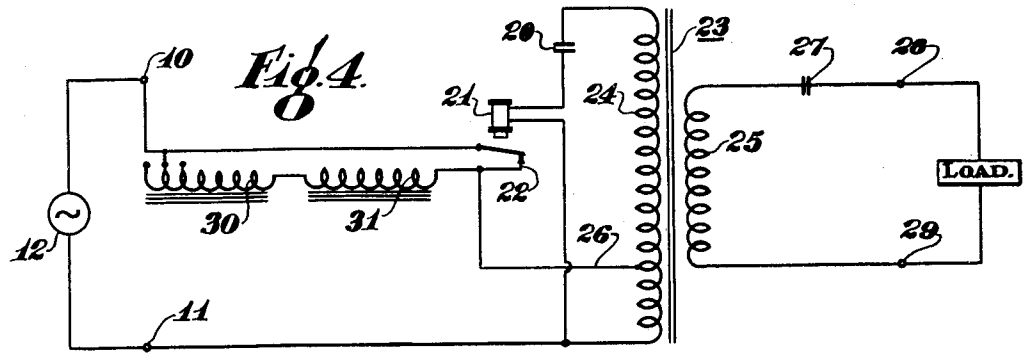
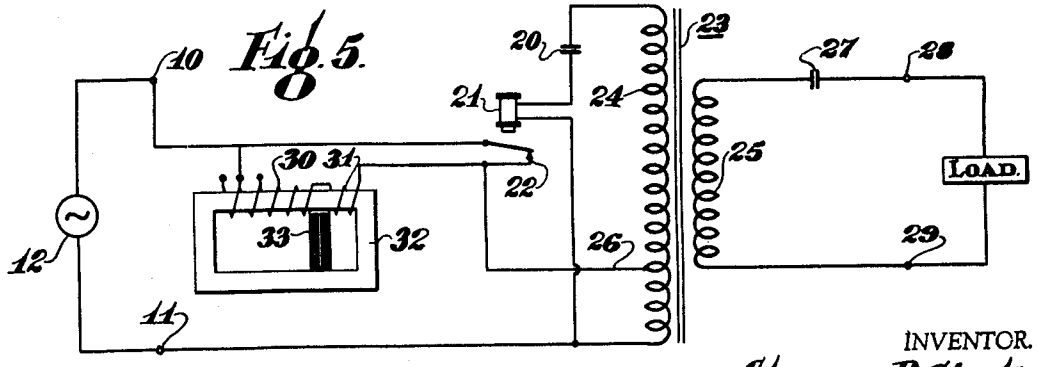


Fig. 5.



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FREQUENCY CHANGING SYSTEM

Filed May 2, 1938 2 Sheets-Sheet 2

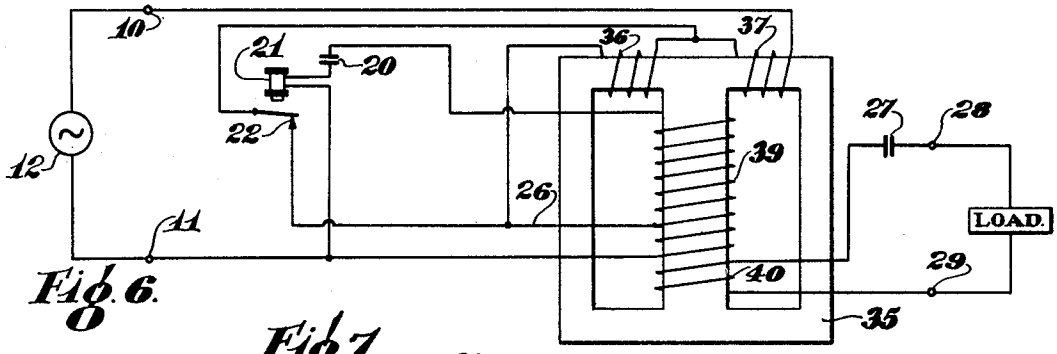


Fig. 6.

Fig. 7.

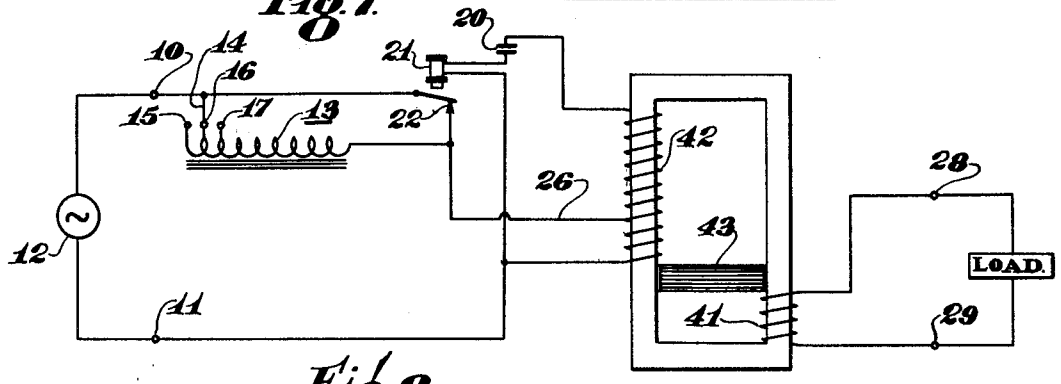


Fig. 8.

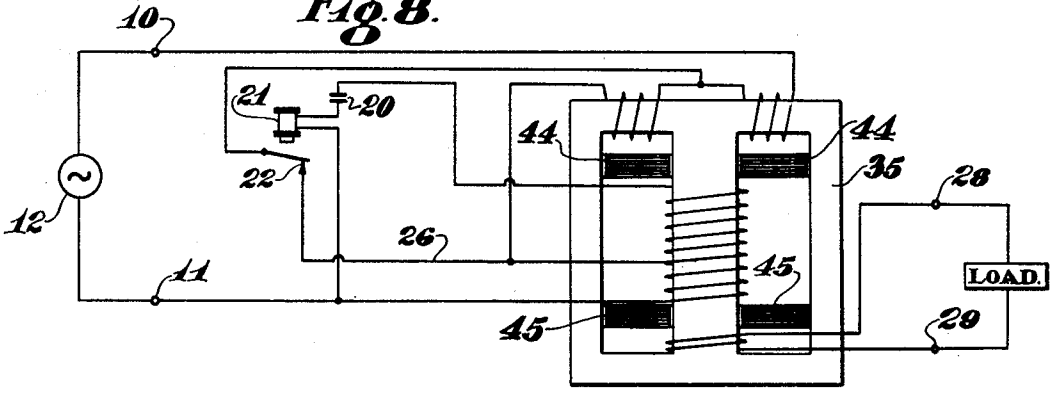
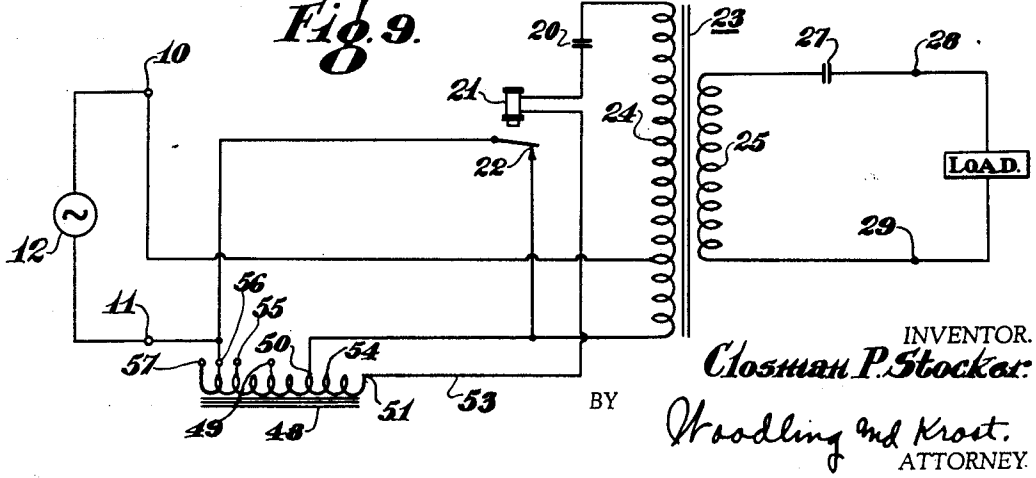


Fig. 9.



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UNITED STATES PATENT OFFICE

2,179,386

FREQUENCY CHANGING SYSTEM

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Application May 2, 1938, Serial No. 205,397

22 Claims. (Cl. 172—281)

This invention relates generally to improvements in frequency changers, and more particularly to improvements in frequency reducers of the static type.

An object of this invention is to provide for improving the operating efficiency of static frequency reducers within particular voltage ranges.

Another object of my invention is to provide for economically extending the working range of a static frequency reducer by minimizing the effect of the maximum and minimum voltage supplied to the static frequency reducers.

Another object of my invention is to provide a common magnetic core for all the operating windings of my static frequency reducer.

A further object of my invention is to provide an output circuit loosely coupled to the frequency reducing circuit.

Another object of my invention is to provide for by-passing the flux set up by the primary winding of the output transformer of the frequency reducing circuit around the secondary output winding.

Another object of my invention is to provide for separating by means of a magnetic shunt the secondary output winding of the output transformer from the primary winding energized by the frequency reducing circuit.

Another object of my invention is to at least partially separate all windings having different functions by magnetic shunts when said windings have a common magnetic core.

A further object of my invention is to provide a static frequency reducer in which leakage reactance of a series choke tends to limit the maximum current flowing in the frequency reducer.

Another object of my invention is to provide for reducing the flux linkage between the secondary output winding and the primary winding of the output transformer.

Another object of my invention is to provide for establishing the voltage-current characteristic of the inductance means of the frequency reducing circuit to eliminate certain frequencies appearing therein.

A further object of my invention is to increase the stability of my frequency reducing circuit on high supply voltages.

Another object of my invention is to reduce the current of supply frequency flowing through the condenser in frequency changing circuits.

Another object of my invention is to cause a substantially symmetrical resultant voltage wave form to be produced in the frequency reducing circuit.

Another object of my invention is to decrease the proportion of beat-frequency generated in the frequency reducer to the desired reduced frequency.

Another object of my invention is to stabilize my frequency reducing circuits when sudden loads or transients are applied.

A further object of my invention is to introduce a voltage of the supply frequency into the condenser circuit of my frequency reducer substantially 180 degrees out of phase with the portion of supply frequency which flows in said condenser circuit.

Another object of my invention is to introduce an additional voltage into the condenser circuit of my frequency reducer.

A further object of my invention is to couple the condenser circuit to the series choke of my frequency reducer in such a way that the phase shift occurring due to load, increases the stability of the circuit.

A further object of my invention is to improve the output wave form of a frequency reducer by minimizing the percentage of second and third harmonics without the use of filters.

Other objects and a fuller understanding of my invention may be had by referring to the following description and claims when read with reference to the accompanying drawings in which like parts are designated by like reference characters, and in which:

Figure 1 shows a static frequency reducer with means to provide efficient operation on a wide range of input voltage;

Figure 2 shows a series choke arranged to have a voltage-current characteristic suitable for my frequency reducer circuit;

Figure 3 shows the current-voltage characteristic curve of a series inductance, with and without high magnetic leakage;

Figure 4 shows a circuit similar to Figure 1 with a modified inductance means;

Figure 5 shows a circuit similar to Figure 1 with a further modified inductance means;

Figure 6 shows all operating windings of the static frequency reducer on the same magnetic core;

Figure 7 shows an output transformer with the output secondary windings loosely coupled to the primary winding of the frequency reducer and a separate series inductance;

Figure 8 shows all operating windings of the frequency reducer mounted on a common core, with the windings separated by means of magnetic shunts; and

Figure 9 shows the condensers circuit back coupled to the series inductance.

The static frequency changer shown in Figure 1 comprises a series inductance means 13, a capacitor 20, and an output transformer 23 having a primary winding 24 and a secondary output winding 25. The inductance means 13 and windings 24 and 25 constitute the operating windings of the static frequency reducer shown in Figure 1. The static frequency reducer shown in Figure 1 is automatically started by means of a relay 21. When the terminals 10 and 11 are connected to an alternating current supply source 12, the capacitor 20 is charged by current flowing through the contact 22 of the relay 21 and the conductor 26 and energizing the primary winding 24. The charging current for the capacitor 20 also flows through the winding of the relay 21. This causes the relay contact to open, and the capacitor 20 then discharges through the winding 24 which causes a current to flow through the inductance means 13. This transient condition establishes oscillations in the frequency reducing circuit at the desired reduced frequency. The operation of a static frequency reducer of which Figure 1 shows a typical example, is further shown and described in my United States Letters Patent, 2,088,618; 2,088,619 and 2,088,620, some of which are self-starting without a relay.

In one embodiment of the frequency reducer of Figure 1, employed to reduce the frequency from 60 cycles to 20 cycles, it was desired to arrange the frequency reducer to operate most satisfactorily upon the voltage supplied in a given community. Ordinarily, such a frequency reducer will operate satisfactorily over voltage ranges between 105 volts and 125 volts. However, where these frequency reducers are used in communities supplied by local power plants or systems, I have found that the voltage supplied to the frequency reducers may be as low as 90 volts or as high as 135 volts. In view of the fact that the impedance of the inductance means 13 changes with current therethrough, it can be readily seen that such a frequency reducer would not operate most efficiently at either the highest or lowest voltages encountered.

By utilizing a tapped series inductance means 13 and lead 14, it is possible to employ the medium tap 16 shown connected in Figure 1 for ordinary commercial supply voltages. However, in communities supplied with exceptionally high voltage, the lead 14 can be shifted from tap 16 to tap 15. In communities where the supply voltage is normally low, the lead 14 would be connected to the tap 17 at the time of installation. I have found that this method readily compensates for the abnormally high or low voltages encountered in a particular community. The tapped arrangement described above can be further extended to provide for operation of my static frequency reducer upon either 110 or 220 volts. By this means I am enabled to eliminate the use of an auxiliary transformer which may be necessary in case it is desired to operate a frequency reducer designed for 110 volts upon a supply voltage of 220 volts. Additional tap or taps may be provided. For example, the tap 16 may be used for operation upon 110 volts and the tap 15 may be used for operation upon 220 volts. For such an arrangement, the tap 17 may be eliminated.

Normally, the inductance means 13 is wound upon a closed magnetic core. It has been found in actual practice, in the case of a frequency reducer employed to reduce the frequency from 60 cycles to 20 cycles, that under conditions of high supply voltage, a new and undesired frequency was generated. Tests disclosed that at abnormally high supply voltages, the saturable inductance means 13 over-saturates and allows an excess of current to flow into the primary winding 24 of the output transformer. When this happens, this new frequency may be a sub-multiple of both the supply frequency and the desired output reduced frequency. In the case I have in mind, the circuit elements caused a sub-multiple frequency of 6⅔ cycles to be generated when connected to a 60-cycle supply course. It will be seen that 6⅔ cycles is the 9th sub-multiple of 60 cycles, the 6th sub-multiple of 40 cycles (40 cycles is caused by beat of 60 cycles and 20 cycles) and the 3rd sub-multiple of 20 cycles. To overcome the generation of this undesirable frequency, I have found that the introduction of leakage into the inductance means 13 will prevent the new sub-multiple frequency from being generated. As will be evident to those skilled in the art, the control of the desirable sub-multiple frequency may be aided by changing the copper to iron ratio of the inductance means 13. By this I mean that for a given inductance, the number of turns of copper wire may be reduced and at the same time the volume of iron in the core stack increased, so that the leakage reactance may be more closely controlled. On tests I have made, I have found that by interleaving the laminations in a given core stack by intervals of four or more rather than by intervals of one sufficient leakage reactance is introduced to limit the saturating current through the inductance means 13 on abnormally high voltages. Figure 2 shows an inductance means with taps 15, 16 and 17 for voltage adjustment and lamination stacking in intervals of four to give the required leakage.

In Figure 3, the curve A shows the voltage-current characteristics when the magnetic core has a minimum of leakage. The curve B shows how the current, through the inductance means 13 is limited with respect to voltage when the leakage reactance is introduced. The voltage-current characteristics may be also altered by using two or more inductances having different saturation characteristics in series, such as shown by the reference characters 30 and 31 in Figures 4 and 5. The resultant voltage-current characteristic of the inductances 30 and 31 may be substantially like that shown by the curve B in Figure 3. In Figure 4, the two inductances 30 and 31 are magnetically separated but in Figure 5, the two inductances 30 and 31 are magnetically coupled by a core 32 and the voltage-current characteristic is governed by a magnetic shunt 33.

I have found that considerable space can be saved and the efficiency increased by combining the inductance means and the output transformer into one unit. An embodiment of this combination is shown in Figure 6, and all the operating windings as mounted upon a common core 35. In this embodiment, the series inductance means is represented by the windings 36 and 37, wound upon the two outer legs of the three-legged magnetic core 35 in such a manner that the current flowing through the windings produces substantialy no flux in the central leg around which is mounted the output transformer having a primary winding 39 and a secondary winding 40. By this method of construction, I am able to save in the total amount of iron used for a specific design. In view of the fact that the core is operated at high flux density and the total iron loss de-

pends upon the watts lost per pound, a more efficient unit can be made with this type of construction.

While I prefer that the windings **36** and **37** shall be balanced to produce substantially no flux in the central leg as described above, this is not a necessary condition for operation. In some cases it may be desirable to cause an unbalance between the windings **36** and **37** in order to provide a feed back flux coupling between the series inductance windings **36** and **37** and the transformer of the condenser circuit. With the unbalanced arrangement, and a slight flux coupling between inductance windings **36** and **37** and the primary winding **39**, I am able to increase the stability of the frequency reducer on high supply voltages. This introduces a voltage of the supply frequency into the primary winding **39** of the condenser circuit. As will be explained in connection with Figure 9, the purpose of this introduced voltage is to reduce the amount of supply current flowing through the condenser. This results in an improved output wave form.

Static types of magnetic frequency reducers such as I described, must be protected against overload on the output circuit. An overload on the output or secondary circuit connected across the terminals **28** and **29** causes oscillations and the frequency reducer to stop. It is therefore desirable to limit the total amount of power it is possible to withdraw from such a frequency reducer. Previous to this time a condenser, such for example, as the condenser **27** shown in Figures 1, 4, 5 and 6, in series with the output circuit has been used for this purpose. I have discovered that it is also possible to limit the maximum amount of energy that can be taken from the secondary or output circuit by means of magnetic leakage in the form of magnetic shunts. Figures 7 and 8 show such a circuit. In Figure 7, the output or secondary winding **41** is separated from the primary winding **42** by a magnetic shunt **43**. By this means, it is possible to reduce the flux linkage between the windings **41** and **42**. In a particular frequency reducing circuit, the primary winding **42** may have as much as 200 volt-amperes in it. However, the secondary output winding **41** may be limited to an output of approximately 20 volt-amperes at unity power factor. This is done by by-passing most of the flux through the shunt **43**. It should be pointed out, however, that in some cases the magnetic shunt **43** may be omitted. This is particularly true if the magnetic core has an excessively long magnetic path similar to laminations used in the construction of some neon sign transformers. It has been found that where the magnetic path is long, sufficient leakage is present to eliminate the necessity for the shunt **43** and still retain the characteristics desired. While I have shown the loose coupling arrangement as incorporated into the output transformer, it will be understood by those skilled in the art that a separate transformer containing the desired leakage characteristics may be used as a coupling between the output circuit and the load. (This arrangement is not shown.)

Figure 8 shows a combination of the arrangements set forth in Figures 6 and 7. In Figure 8, all of the operating windings of the frequency reducer are upon the common core **35**, and further, each of the operating windings is at least partially separated by means of the magnetic shunts **44** and **45** from each of the other operating windings. With this arrangement, I combine all the advantages of arrangements shown and disclosed in Figures 6 and 7.

Figure 9 shows a frequency reducer with a further modified stabilizing arrangement in which I back-couple the condenser circuit to the series inductance means **48**. By referring to Figures 1 and 9, it will be noted that the only difference is, that in Figure 9 the winding **54** between points **50** and **51** on the series inductance means **48** has been added in series with the circuit containing the condenser **20**, and the electrical position of the inductance means **48** has been shifted to the lower lead of the primary winding **24** instead of being positioned in series with the intermediate lead **26**.

In a circuit as per Figure 1 an appreciable amount of current of the supply frequency flows through the condenser **20**. In a frequency reducing circuit the supply frequency may be an harmonic of the reduced frequency. To take a specific example let it be assumed that a commercial frequency of 60 cycles is supplied to my frequency reducer. The output frequency of the frequency reducer is 20 cycles. This would mean that while the reduced frequency of 20 cycles is flowing through the condenser **20**, the supply voltage also causes current to flow through the condenser **20** having a frequency the same as the supply frequency. As is well known, a beat-frequency occurs and in this case the beat-frequency is 40 cycles.

Through a series of tests, I have determined that the 20-cycle current component (reduced frequency) is substantially constant over a wide range of supply voltages, but that the 60-cycle current component varies with a change in the supply voltage, causing a resultant increase in combined currents. To take a specific example, the 20-cycle current component is approximately 1 ampere and the 60-cycle current component is approximately ½ ampere at 115 volts, with a 60-cycle supply. Under this condition, the circuit is stable. If the supply 60-cycle voltage is increased to 135 volts, the 20-cycle current component remains substantially constant at 1 ampere while the 60-cycle current component may increase to 1 ampere. Under this condition the circuit becomes unstable. While I do not want to be bound by a theory, I believe that this instability results from the fact that the beat-frequency of 40 cycles becomes greater in amplitude and as previously explained, the opportunity for the sub-multiple frequency of 6⅔ cycles to appear is increased.

By back-coupling the condenser circuit to the series inductance means **48**, I am able to introduce sufficient voltage of the 60-cycle source in series with the condenser **20** and approximately 180 degrees out of phase to substantially eliminate the 60-cycle current component flowing through the condenser. I prefer to introduce only enough of the 60-cycle voltage by means of the series winding **54** on the inductance means **48** to nullify the normal 60-cycle current component flowing through the condenser **20**. If the winding **34** is increased beyond this value, the output voltage wave will be dimpled due to the third harmonic being substantially 180 degrees out of phase with the voltage of the reduced frequency. It should be pointed out that the output voltage wave may be peaked by the third harmonic by moving the lead **53** to some points such as **49**, **55**, **56** or **57**, on series inductance means **48**. In some cases, this may be an advantage, but in my proposed arrangement, I

desire to eliminate as much of the second and third harmonics as possible from the output voltage wave. By introducing a voltage of the supply frequency substantially 180 degrees out of phase with the supply frequency normally in the condenser circuit, I am able to achieve this result.

A frequency reducer having a back coupled inductance means such as I have described, shows greater increased stability on high supply voltages. This is probably due to the fact that less current of the supply frequency appears in the condenser circuit as described above. However, another possible reason for this increased stability is the fact that the saturation of series inductance means varies less with the supply voltage variation. In other words, the 20-cycle current component through the condenser **20** tends to maintain a more constant degree of saturation in the inductance means **20**. Since it is possible to extend the normal operating range towards the upper voltage supply limits, it is possible to obtain a higher output power within a given supply voltage range.

By utilizing the back-coupled inductance means as shown in Figure 9, the frequency reducing circuit possesses greater stability when transient loads are applied. I believe this is due to the fact that a voltage phase shift occurs which is favorable to the stability of the circuit. Specifically, there seems to be less out of phase voltage shift between the 20-cycle voltage component in the condenser circuit and the applied 60-cycle voltage. Such a phase shift tends to allow more power to be delivered to the output circuit.

The back-coupled arrangement shown in Figure 9 and the feed back flux coupling shown in Figure 6 operate upon substantially the same principle, except that in Figure 6, the coupling is embodied in a common core and in Figure 9, the coupling is embodied in two separate cores.

Although I have described my invention with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example, and the numerous changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

I claim as my invention:

1. A static frequency reducer adapted to be energized by an alternating circuit comprising a capacitor and a non-linear inductance arranged to oscillate at a reduced frequency, said non-linear inductance having magnetic core means comprising a plurality of portions in which at least two of said portions operate at different flux densities to substantially prevent the appearance of sub-multiple frequencies of the reduced frequency.

2. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit having a capacitor and a non-linear inductance arranged to oscillate at a reduced frequency, said inductance comprising a plurality of inductance means connected in series, each of said inductance means having different saturation characteristics to produce a combined inductance which is substantially non-linear and which prevents the appearance of sub-multiple frequencies of the reduced frequency.

3. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit and output means coupled by magnetic core means to said oscillating circuit to limit the maximum output load current, said magnetic core means comprising a plurality of portions in which at least two of said portions operate at different flux densities to stabilize the main oscillating circuit.

4. A static frequency reduced adapted to be energized by an alternating current supply source comprising an oscillating circuit having a capacitor and a non-linear inductance, additional winding means on said inductance in series with the supply source to introduce an additional voltage into the capacitor circuit for operating the reducer over a wide supply voltage range.

5. A static frequency reducer adapted to be coupled to an alternating current supply source by means of a series inductance, said series inductance being part of a main oscillating circuit and equipped with an additional winding for enlarging the operating supply voltage range over which the frequency reduced may be operated.

6. A static frequency reducer adapted to be energized by an alternating current supply source comprising, an oscillating circuit as the main frequency reducer circuit, said static frequency reducer having an output circuit magnetically coupled by magnetic core means to the main frequency reducing circuit, said magnetic core means comprising a plurality of portions in which at least two of said portions operate at different flux densities to stabilize the main oscillating circuit.

7. A static frequency reducer, adapted to be energized by an alternating current supply source, comprising an oscillating circuit as the main frequency reducing circuit, said static frequency reducer having an output circuit magnetically coupled to the main frequency reducer circuit, and magnetic shunt means for establishing a decreased flux linkage between the output circuit and main frequency changing circuit.

8. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit and output means each having an operating winding, a saturable common core, all operating windings being mounted upon the common saturable core.

9. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit and output means, each having an operating winding of different function, a saturable common core, all operating windings being mounted upon the common saturable core, and magnetic shunt means mounted on the common core to partially separate the windings having different functions.

10. A static frequency reducer adapted to be energized by an alternating current supply source comprising a saturable common core, an oscillating circuit and output means, each having an operating winding means mounted upon the common saturable core, and magnetic shunt means on the common core to partially separate the winding means of said output circuit from the winding means of the oscillating circuit.

11. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit including a condenser and a non-linear inductance, said non-linear inductance having an additional winding in series with the condenser, said additional winding producing a voltage of the supply frequency approximately 180 degrees out of phase with the voltage of the supply frequency which flows through the condenser circuit.

12. A static frequency reducer adapted to be

energized by an alternating current supply source comprising a series choke and an output transformer each containing a saturable magnetic core and a condenser combined to form an oscillating circuit, said series choke being so connected with respect to the condenser as to substantially eliminate the current due to voltage of the supply frequency flowing through the condenser circuit.

13. A static frequency reducer adapted to be energized by an alternating current supply source comprising a common core, an oscillating circuit having an inductance winding and a transformer, said transformer having a primary and a secondary winding, all of said windings being mounted upon the common core, said inductance winding and said primary winding being magnetically associated to provide a feed back flux coupling therebetween.

14. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit including a condenser and non-linear inductance means arranged to oscillate at a reduced frequency, and means for introducing an additional voltage in series with the condenser, said additional voltage having a frequency the same as the supply frequency and approximately 180 degrees out of phase with the voltage of the supply frequency which flows through the condenser circuit.

15. A static frequency reducer having a main oscillating circuit adapted to be coupled to an alternating current supply source by a plurality of inductances, said plurality of inductances being part of the main oscillating reducing circuit, at least one of said inductances having a characteristic to prevent the appearance of sub-multiple frequencies of the reduced frequency.

16. A static frequency reducer of the type described having a main oscillating reducing circuit comprising a condenser and a non-linear inductance, and means for back coupling the condenser to the inductance to stabilize the operation of the oscillating circuit.

17. A static frequency reducer having a main oscillating reducing circuit coupled to an alternating current supply source by a plurality of inductance windings mounted upon a core having a magnetic shunt separating the windings to prevent the appearance of sub-multiple frequencies of the reduced frequency.

18. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit including a condenser and a non-linear inductance, said non-linear inductance having an additional winding in series with the condenser, said additional winding producing a voltage of the supply frequency out of phase with the voltage of the supply frequency which flows through the condenser circuit.

19. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit including a condenser and non-linear inductance means arranged to oscillate at a reduced frequency, and means for introducing an additional voltage in series with the condenser, said additional voltage having a frequency the same as the supply frequency and out of phase with the voltage of the supply frequency which flows through the condenser circuit.

20. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit including a condenser and non-linear inductance means arranged to oscillate at a reduced frequency, and means for introducing an additional voltage in series with the condenser, said additional voltage having a frequency the same as the supply frequency and modifying the supply frequency which flows through the condenser circuit.

21. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit including a condenser and non-linear inductance means arranged to oscillate at a reduced frequency, and means for introducing an additional voltage in series with the condenser, said additional voltage having a frequency the same as the supply frequency and adding to the supply frequency which flows through the condenser circuit.

22. A static frequency reducer adapted to be energized by an alternating current supply source comprising an oscillating circuit including a condenser and non-linear inductance means arranged to oscillate at a reduced frequency, and means for introducing an additional voltage in series with the condenser, said additional voltage having a frequency the same as the supply frequency and subtracting from the supply frequency which flows through the condenser circuit.

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