

[54] **FILTER CIRCUIT FOR CORONA DETECTION**
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1,943,392 1/1934 Paine et al. 324/54
3,015,774 1/1962 Eigen 324/54

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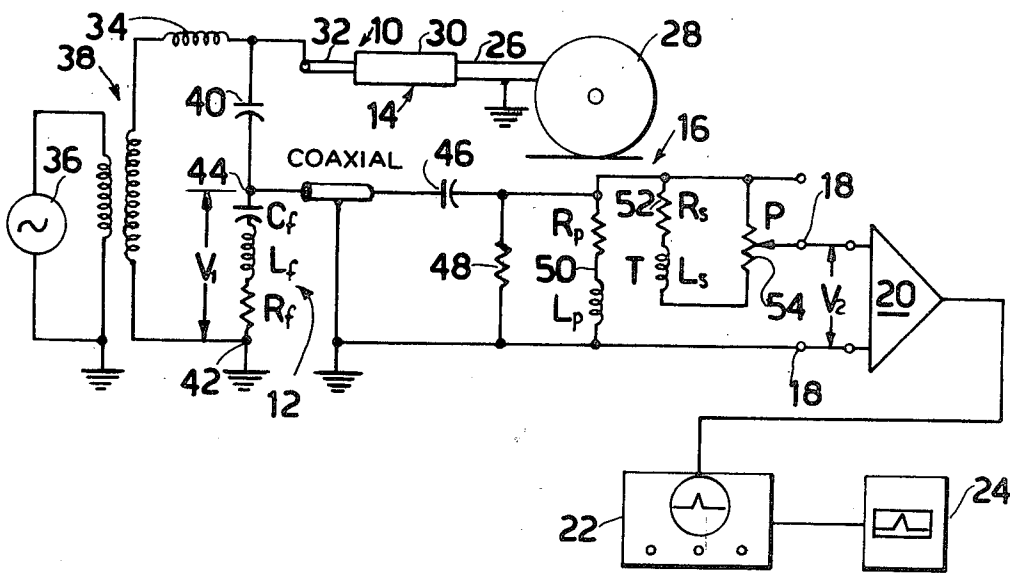
[57] **ABSTRACT**

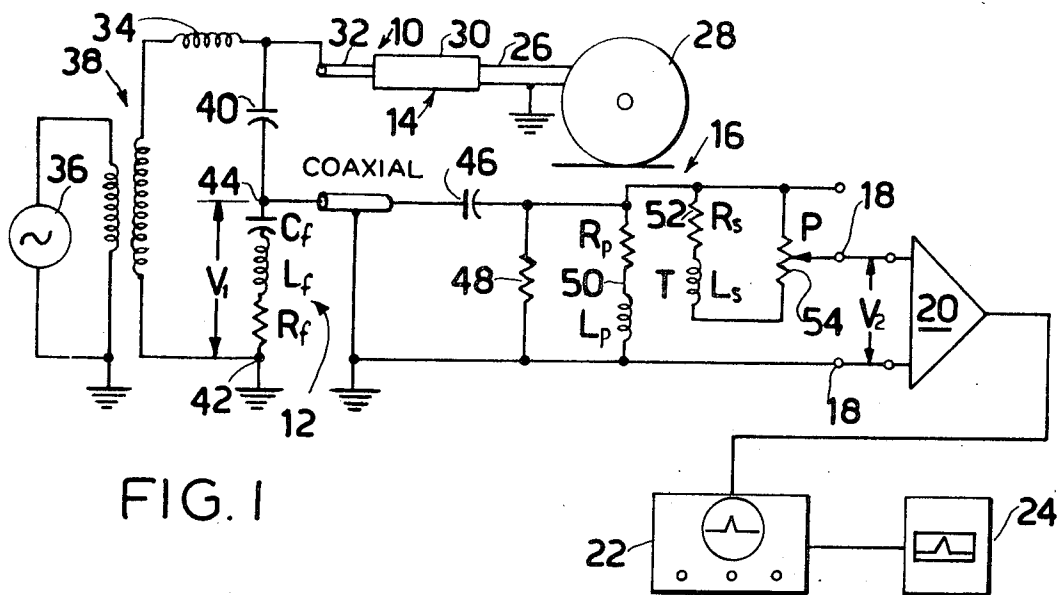
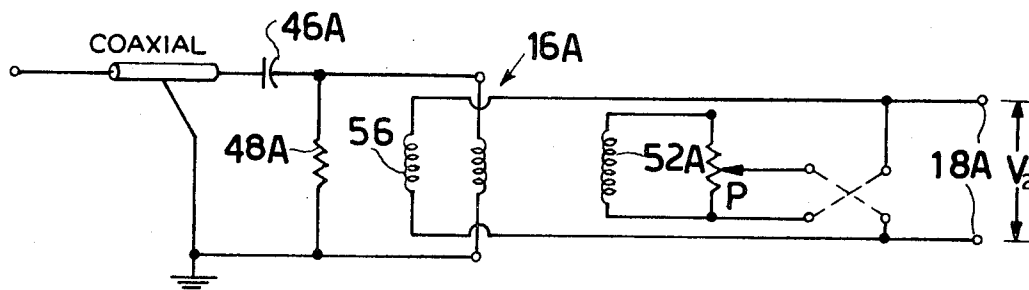
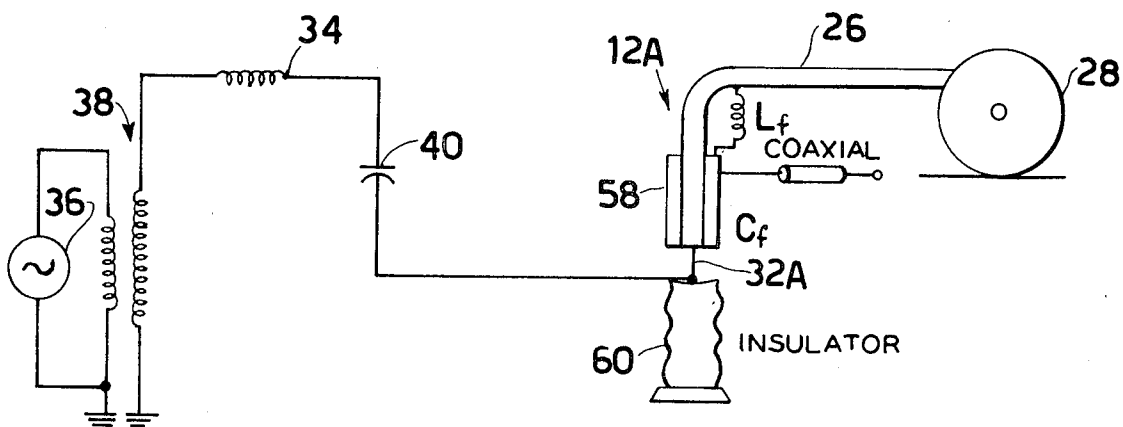
A filter network for providing essentially optimum resolution of pulse response in the detection of high frequency corona discharge, including a high pass filter for removing the low frequency power line signal and its harmonics, and a low pass lossy transformer which introduces a low frequency bucking voltage in a subsequent stage of detection to balance out any residual low frequency signals still present, thereby providing improved resolution and sensitivity in the detection of corona discharge.

8 Claims, 3 Drawing Figures

[56] **References Cited**
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FILTER CIRCUIT FOR CORONA DETECTION

This invention relates to corona discharge detection in solid-dielectric or insulated cables. More specifically, this invention relates to a power-separator filter capable of providing a pulse response affording optimum resolution damping, representative of "real" corona discharge in the cable system.

Ideally, insulated cables should be manufactured void-free for stable operation and long life. If a void is present within the length of cable being tested, application of a high voltage will cause ionization of gas trapped within the void resulting in a high frequency discharge known as corona discharge.

Accurate detection of corona discharge in solid-dielectric cables, utilizing e.g. crosslinked polyethylene and rubber insulation, is important in determining cable quality. A conventional method for determining corona discharge utilizes a power-separator filter to detect the major portion of the corona discharge energy occurring predominantly in the kHz frequency range. This major portion of the corona discharge energy is usually measured over a narrow frequency band; detection bands at 35 kHz and 70 kHz have been found to be practical for commercial application. Broad band detection has been employed with some success, but increased band width significantly decreases detector sensitivity.

It is desirable that the response of the apparatus employed for corona discharge detection provide optimum resolution and sensitivity. The "alpha" response, comprising one type of response which is generally regarded as desirable and which is specified in the cable industry, defines an initial maximum amplitude half-cycle of an oscillatory wave, followed by highly attenuated or damped subsequent half-cycles.

Conventional corona discharge detectors have generally employed LC networks which produce an oscillatory response and differentiate the desired high frequency components of the input signal. Differentiation modifies and distorts the signal shape and magnitude, producing both positive and negative responses. Further, since the response is not attenuated after the initial pulse, resolution is affected and pyramiding may occur, leading to additive errors in determining "real" corona discharge.

Apparatus for corona discharge detection are disclosed in Letters U.S. Pat. No. 3,015,774, issued to D. Eigen, and Letters U.S. Pat. No. 3,229,199, issued to R. C. Mildner. Eigen discloses the use of a conventional high pass filter for transmitting high frequency corona discharge currents to a primary amplifier. A remote antenna capable of detecting radiated noise and interference is coupled to a secondary amplifier. The signals from the secondary amplifier are utilized to buck the common noise and interference signals present in the primary amplifier. There is no teaching in Eigen, however, to utilize a low pass lossy transformer in the detector circuit to eliminate residual low frequency components in detecting an optimum pulse response, representing "real" corona discharge.

Mildner discloses the utilization of a pair of electrodes in conjunction with a pair of intermediate frequency band pass rejection filters. When a void is present in the cable being tested, the resulting corona discharge causes an unbalance in the capacitance of one of the electrodes, thereby producing a signal which indicates the presence of a void. Mildner is not primarily

concerned with the optimization and sensitivity of the pulse response or corona display.

It is an object of the present invention to provide an apparatus which is capable of providing substantially optimum resolution and sensitivity in the detection of "real" corona discharge.

It is a further object to provide an apparatus for eliminating any residual low frequency components which are present in a resultant corona discharge.

It is a further object to provide such an apparatus without employing differentiation.

Briefly, the present apparatus provides for improved resolution of pulse response in the detection of high frequency corona discharge. A high pass filter rejects the low frequency line signal and its harmonics which are present in the resultant corona discharge. A low pass lossy transformer is electrically coupled to the high pass filter to provide a bucking voltage which balances out or subtracts any residual low frequency signals still present in the high pass filter output signal, thereby providing an essentially undistorted pulse response representing the energy and magnitude of the high frequency corona discharge.

Other objects, aspects and advantages of the present invention will be more fully understood when the detailed description is considered in conjunction with the drawings as follows:

FIG. 1 shows one embodiment of the present invention employing an oil-filled terminal system for corona detection;

FIG. 2 shows a modified low pass lossy transformer including a tertiary winding which constitutes an additional refinement which may be utilized to improve the quality of pulse response in corona detection of the cable system in FIG. 1 employing an oil-filled termination assembly; and

FIG. 3 shows a capacitance graded terminal cable system capable of being used with the low pass lossy transformers shown in FIGS. 1 and 2.

Referring to FIG. 1, a system 10 for corona discharge detection is shown. A series tuned high pass filter 12 is connected in parallel with the length of insulated cable, generally indicated at 14, to be tested for corona discharge. A low pass lossy transformer 16 (T) is electrically coupled to the high pass filter 12 for providing a bucking voltage to balance out or subtract any residual low frequency components present in the input signal (V_1), which were not removed by the high pass filter 12, thereby providing a substantially undistorted pulse response (V_2) to real corona discharge at the output terminals 18.

The output terminals 18 may be coupled to a following amplifier 20 and the amplifier output is transmitted to conventional detectors, such as a cathode ray oscilloscope 22, and/or a recording oscillograph 24.

Generally, the end of the insulated cable 26 to be tested is unwound from a conventional reel 28 and arranged in an oil-filled terminal 30. The insulated portion (cable shield) of the length of tested cable 14 is grounded and the conducting portion (conductor) 32 of the insulated cable 26 receives a high voltage signal through a coupling inductor or choke 34 (1,500 mH). A conventional line voltage source 36 connected across a step-up transformer 38, supplies the high voltage energy to the choke 34 and ultimately to the length of tested cable 14.

A high voltage blocking capacitor 40 (0.003 μ F) and the high pass filter 12, including C_f (480 μ F), L_f (24 mH) and its inherent resistance R_m (0.26 ohms) are connected in parallel across the length of tested cable 14. The series tuned high pass filter 12 has one terminal 42 grounded and the other terminal 44 coaxially coupled to the low pass lossy transformer 16 through coupling capacitor 46 (0.001 μ F) and primary shunting resistance 48 (600 ohms).

The low pass lossy transformer 16 has balanced primary and secondary windings 50 and 52, respectively, having a 1:1 turns ratio. Further, the secondary winding 52 has a high rejection ratio of higher frequencies. The primary winding 50, including L_p (77 mH) and R_p (7 ohms), is connected between ground and the high pass filter 12 through coupling capacitor 46. The secondary winding 52, including L_s (75 mH) and R_s (30 ohms), is connected across a potentiometer 54 to provide a variable output voltage pulse signal (V_2) affording optimum resolution of the real corona discharge, as measured between the grounded primary winding and the adjustable potentiometer setting.

The secondary winding 52 exhibits a limited frequency response and introduces a bucking voltage which balances out or subtracts any residual low frequency components appearing therein while not affecting the high frequency components being detected. Thus, the output voltage (V_2) provides a measurement of real corona discharge.

The output terminals 18 are coupled to the input of the following amplifier 20. The amplifier 20 has impedance matching characteristics for maximum power transfer and for essentially distortionless transmission of the output voltage (V_2) to the oscilloscope 22. It should be noted that various types of detectors may be employed; it may be advantageous to use an analog charge meter or calibrated recorder.

Referring to FIG. 2, a low pass lossy transformer 16A is shown having an additional primary or tertiary winding 56 to eliminate the effects of phase shift and increase the high frequency rejection ratio while improving the efficiency and frequency response. The primary tertiary winding 56 has only sufficient band width to pass the low frequency signals, which serve to buck or balance out residual low frequency components of the detected signal at the secondary winding 52A, thereby providing a measurement of real corona discharge (V_2) across output terminals 18A. The apparatus shown in FIG. 2 may be readily employed in the detection of corona discharge in a cable system as shown in FIG. 1 by simply removing the filter apparatus shown in FIG. 1 and inserting the apparatus shown in FIG. 2 between terminals 44 and 18.

Referring to FIG. 3, an alternate embodiment is shown for the series tuned high pass filter 12A when used with a capacitance-graded terminal 58, rather than with the oil-filled terminal 30 shown in FIG. 1. The inductor L_2 of the series tuned high pass filter 12A is connected directly between the capacitance-graded terminal 58 and the cable insulation. The capacitance-graded terminal 58 and conductor 32A rest on insulator 60. The capacitance-graded terminal 58 may be utilized with either of the filter apparatus embodiments shown in FIGS. 1 or 2.

It should be noted that it may be advantageous to arrange a plurality of low pass lossy transformers in cas-

cade to improve efficiency and increase the high frequency rejection ratio of the secondary winding.

During operation of the system 10 shown in FIG. 1, the line voltage signal is applied across the step-up transformer 38, and the resultant high voltage signal is applied to the conducting portion 32 of the length of tested cable 14 through coupling inductor 34. Any resultant corona discharge signal will include the "real" corona discharge, as well as low frequency components, including the line or supply voltage signal and its harmonics. The resultant signal is applied across the high voltage blocking capacitor 49 and the high pass filter 12. The high pass filter 12 substantially rejects the low frequency signal components. However, due to the broad tuning characteristics of the high pass filter 12, residual low frequency components remain in the resultant corona discharge (V_1).

The coupling capacitor 43 connected between one terminal 44 of the high pass filter 12 and the primary winding 50 of the low pass lossy transformer 16 passes the resultant corona discharge signal, including the residual low frequency components, from the high pass filter 12 to the transformer 16.

The low pass lossy transformer is balanced with a secondary winding 52 having a high rejection ratio of higher frequencies to provide a bucking voltage which opposes, thereby subtracting out, the residual low frequency components in the detected corona pulse response to provide an output voltage pulse response (V_2) having optimum resolution representative of real corona discharge occurring in the cable system being measured.

The pulse response representative of the high frequency corona discharge is generally amplified and transmitted to a detector to provide a visual indication of the type and magnitude of the real corona discharge.

Utilization of the bucking transformer 16 coupled to the high pass filter 12 advantageously provides detection of real corona discharge without the attendant distortion produced by differentiation.

It should be understood by one skilled in the art that various modifications may be made to the present invention which are within the spirit and scope thereof as described in the specification and defined in the appended claims.

What is claimed is:

1. Apparatus for providing substantially optimum resolution of high frequency corona discharge in an insulated cable comprising:

a high pass filter for substantially rejecting the low frequency line signal and its harmonics present in a resultant corona discharge; and

a low pass lossy transformer electrically coupled to said high pass filter for introducing a bucking voltage to balance out any residual low frequency signals resulting from the broad tuning characteristics of the high pass filter to provide optimum resolution and sensitivity of pulse response in the detection of high frequency corona discharge.

2. Apparatus for providing substantially optimum resolution of high frequency corona discharge in response to a line signal applied to an insulated cable comprising:

a high pass filter arranged to shunt the line signal and its harmonics to ground;

means for coupling said high pass filter to a low pass lossy transformer to transmit the high frequency

corona discharge and any residual low frequency signals thereto;

said low pass lossy transformer including primary and secondary windings, said primary winding having one terminal connected to said coupling means and the other terminal connected to ground; and

a potentiometer connected in parallel across said secondary winding, to provide a variable output voltage pulse representative of high frequency corona discharge between ground and the adjustable potentiometer setting.

3. Apparatus for detection of corona discharge in an insulated cable comprising:

a high pass filter;

a high voltage blocking capacitor connected in series with said high pass filter;

said high pass filter and said blocking capacitor capable of being arranged in parallel with the insulated cable being tested, said high pass filter adapted to substantially remove the low frequency line signal and its harmonics present in the resultant corona discharge;

a coupling capacitor connecting said high pass filter to a low pass lossy transformer to transmit the high frequency corona discharge and any residual low frequency signals thereto;

said low pass lossy transformer having a secondary winding with a limited frequency response to introduce a bucking voltage to balance out any residual low frequency signals, thereby providing substantially optimum resolution of the high frequency corona discharge.

4. Apparatus for corona detection of the type having means for applying a high voltage signal to a length of insulated cable which is to be tested for corona discharge, a high pass filter for rejecting low frequency signals present in a resultant corona discharge, and a detector capable of indicating corona discharge, wherein the improvement comprises:

a low pass lossy transformer electrically coupled to the high pass filter for introducing a bucking voltage to balance out any residual low frequency signals to provide optimum resolution of the pulse response representative of high frequency corona discharge which is transmitted to the detector.

5. Apparatus for corona detection of the type having means for applying a high voltage signal to a length of insulated cable which is to be tested for corona discharge, a high pass filter for rejecting low frequency signals present in a resultant corona discharge, and a detector capable of indicating corona discharge as claimed in claim 4 including:

a plurality of said low pass lossy transformers connected in cascade.

6. Apparatus for corona detection of the type having means for applying a high voltage signal to a length of insulated cable which is to be tested for corona discharge, a high pass filter means for rejecting low frequency signals present in a resultant corona discharge, and a detector capable of indicating a corona discharge as claimed in claim 4 wherein:

said low pass lossy transformer includes a tertiary winding for more selective transmission of the desired high frequency corona discharge band to eliminate the effects of phase shift while improving the efficiency, resolution and frequency response.

7. Apparatus for corona detection of the type having means for applying a high voltage signal to a length of insulated cable which is to be tested for corona discharge, a high pass filter for rejecting low frequency signals present in a resultant corona discharge, and a detector capable of indicating a corona discharge as claimed in claim 6 including:

a plurality of said low pass lossy transformers connected in cascade.

8. Apparatus for corona detection of the type having means for applying a high voltage signal to a length of insulated cable which is to be tested for corona discharge, a high pass filter for rejecting low frequency signals present in a resultant corona discharge, and a detector capable of indicating a corona discharge as claimed in claim 4 including:

amplifier means electrically coupled to the output of said low pass lossy transformer, adapted to match the output impedance thereof, providing substantially distortionless transmission of the pulse response representative of the high frequency corona discharge band to the detector.

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