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(54) Title: AN ON-LINE DIAGNOSTIC METHOD FOR HEALTH MONITORING OF A TRANSFORMER

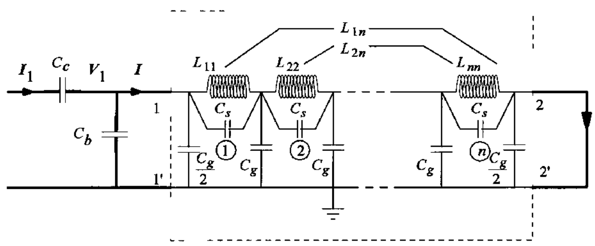

Fig 1

(57) Abstract: An on-line diagnostic method for health monitoring of a transformer. In the case of a single phase or three phase star connected transformer deformations in the winding are determined by representing the transformer winding as a lumped parameter circuit and dividing the winding into at least two sections. A first set of fingerprint values are generated to determine the location of the deformed section of the winding and the type of deformation. A second set of finger print values are generated to determine the extent of deformation of the deformed section. The location and extent of radial or axial deformation or combination of both radial and axial deformation in the winding are then determined. The change in the capacitance of the bushing of the transformer connected at the line end of the winding is also determined. The state of the insulation system of the transformer is determined by detecting partial discharge pulses in the transformer winding. The change in the dielectric characteristics of the insulation system of the transformer is detected on the basis of phase angle difference.

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TITLE OF THE INVENTION

An on-line diagnostic method for health monitoring of a transformer

FIELD OF THE INVENTION

This invention relates to an on-line diagnostic method for health monitoring of a transformer.

BACKGROUND OF THE INVENTION

Transformers are used to step up or step down voltage levels in power systems and are important components of power systems. Health monitoring of transformers is extremely important to ensure smooth and efficient operation of the transformers and to prevent damage and breakdown of the transformers. Several causative factors like deformations in the transformer winding (high voltage or HV winding or low voltage or LV winding), change in capacitance of the bushing of the transformer or deteriorations in the insulation system of the transformer due to partial discharges or change in dielectric strength can reduce the performance efficiency of the transformer and cause damage and breakdown of the transformer. Frequency Response Analysis (FRA) is a widely used method for detection of deformations in the transformer winding (Secue, J. R. and Momembello E., "Sweep frequency response analysis (SFRA) for the assessment of winding displacements and deformation in power transformers," *Electrical Power System Research*, vol. 78, 2008, pp. 1119-1 128.) In this method, the sweep frequency response of the winding is obtained as a fingerprint graph. At the time of detection of deformations in the winding, a set of measurements are again made to obtain frequency response. The graph representing the subsequent measurements is superimposed on the fingerprint graph and the differences, if any, between the curves of the two graphs are examined for deformations. Examination / analysis of the differences between the two graphs is subjective and may vary from person to person and may not provide a proper and accurate evaluation of the deformations. Further, differences between the two graphs will only indicate presence of deformation, if any, but will not indicate the location, nature and extent of the deformation straightaway. In our patent application No 1893/MUM/2007 we have described a method for determining deformations in a transformer winding in an accurate and reliable manner. One method for measuring changes in capacitance of transformer bushing is based on measuring its power factor on-line using sensors on the bushing capacitance taps to measure leakage currents. Another technique for determining change in the bushing capacitance of three phase transformers, sums up the bushing currents from the three phases and plots them on a polar plot. Any shift in the resultant currents indicates a change in capacitance or dissipation factor of one of the bushings (IEEE Standard-62, 1995). Acoustic method is used for detecting partial discharges (PD) in the transformer. This method comprises sensing mechanical vibrations generated by PD pulses using acoustic sensors mounted either on the transformer tank wall or in the oil inside the transformer tank. If multiple sensors are used, the PD can be located based on the arrival time of the pulses at the sensors (IEEE Standard C57. 113-1991, Revised 2002). The sensitivity of the test is dependent on the location of the PD since the signal is attenuated by the oil and winding structure. PD is also known to be detected indirectly using chemical techniques involving measurement of degradation products produced by the PD. Such techniques do not give any information about location of PD. PD causes high-frequency low-amplitude disturbances on the current waveforms, which can be detected electrically. The electrical PD signals are measured in bushing tap current and neutral current. Another technique applied to detect PD in gas insulated substations is based on ultra-high-frequency (UHF) signals (typically 1-2 GHz). Methods like dielectric breakdown test, moisture content test, dissolved gas analysis (DGA) test or power factor test are used for determining the dielectric strength and status of the insulation system of the transformer (IEEE Standard C57.104, 1991).

OBJECTS OF THE INVENTION

An object of the invention is to provide an on-line diagnostic method for health monitoring of a transformer, which method continuously monitors multiple health factors of the transformer in service condition without having to isolate the transformer from the power system in which it is connected so as to give a comprehensive health status of the transformer.

Another object of the invention is to provide an on-line diagnostic method for health monitoring of a transformer, which method is accurate and reliable and effective in determining the health factors of the transformer.

Another object of the invention is to provide an on-line diagnostic method for health monitoring of a transformer, which method eliminates the down time required for the diagnosis of the health condition of the transformer.

Another object of the invention is to provide an on-line diagnostic method for health monitoring of a transformer, which method can help to understand the dynamic behaviour of the transformer subjected to short circuit.

Another object of the invention is to provide an on-line diagnostic method for health monitoring of a transformer, which method is simple and easy to carry out and is economical.

DETAILED DESCRIPTION OF THE INVENTION

According to the invention there is provided an on-line diagnostic method for health monitoring of a single phase transformer or a three phase star connected transformer, the method comprising the following steps :

A) determining deformations in the transformer winding by

A-I) representing the transformer winding as a lumped parameter circuit and dividing the winding into at least two sections n;

A-2) generating a first set of fingerprint values by

(i) measuring the high frequency terminal current I_1 at one end of the winding when a constant sinusoidal voltage V_1 is applied between one end of the winding and one ground terminal at a high frequency in a band of frequencies at which the terminal impedance of the winding remains capacitive, while keeping the other end of the winding and the other ground terminal connected; measuring the high frequency terminal current I_2 flowing from other end of the winding to the other ground terminal at the same high frequency, while keeping the same voltage V_1 between one end of the winding and the one ground terminal; and measuring the phase angle θ_1 between I_1 and V_1, the application of high frequency voltage and detection of high frequency currents being carried out by employing known procedures of coupling and detecting such signals superimposed on power frequency voltage / current components;

ii) calculating the sectional series capacitance (C_s) and the sectional ground capacitance (C_g) of each of the different sections n of the winding using the values of I_1, I_2 and V_1 obtained in step A-2(i) and the value of bushing capacitance C_b, provided by the transformer manufacturer as follows:

$$I = I_1 - \omega C_b V_1$$

$$N = \begin{bmatrix} \frac{I}{I_2} & \frac{\omega V_1}{I_2} \\ \frac{\left(I^2 - I_2^2\right)}{\omega V_1 I_2} & \frac{I}{I_2} \end{bmatrix}^{\frac{1}{n}}$$

$$C_s = \frac{1}{N(\mathrm{i}, 2)}$$

$$C_g = 2[\mathrm{Q}N(\mathrm{I}, 1) - C_s]$$

where ω is the selected high frequency in rad/sec,

n is number of sections,

N is 2 x 2 matrix obtained from measurements in step A-2(i) and $N(\mathrm{I},\mathrm{I})$ and $N(1,2)$ are the first and second element of row one of matrix N,

$V_\backslash$ is constant sinusoidal voltage applied in volts, and

$I_\backslash$ *and h* are two terminal currents in amperes

(iii) simulating a range of deformations in each of the sections of the winding by changing the sectional ground capacitance C_g and sectional series capacitance C_s obtained in step A-2(ii) by predetermined percentages and generating simulated terminal current values $/_1{}^I$ and h^1 under the same conditions and procedures corresponding to $I_\backslash$ and h, respectively in step A-2(i) for each change of the sectional ground capacitance and sectional series capacitance;

(iv) calculating current deviation coefficient which is a non-limiting function of $(I\backslash - I_1{}^I)/(I_2 - h')$ for each of the sections of the winding for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained in step A-2(iii) to form a first look up table of current deviation coefficients; and forming a first set of finger print values using the current deviation coefficients, the first set of finger print values indicating the location of the deformed section of the winding and the type of deformation;

A-3) generating a second set of finger print values by calculating the difference between I_1 obtained in step A-2(i) and I_1^{I} obtained in step A-2(iii) and between I_2 obtained in step A-2 (i) and I_2^{y} obtained in step A-2 (iii) for each of the sections of the winding for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained in step A-2 (iii); forming a second lookup table of differences and forming a second set of finger print values using the differences, the second set of fingerprint values indicating the extent of deformation of the deformed section; and

A-4) determining the location and extent of radial or axial deformation or combination of both radial and axial deformation in the winding by

(i) measuring the terminal current values I_1'' and I_2'' as explained in step A-2(i) at the same high frequency voltage V_1;

(ii) comparing the values of I_1 with I_1^{11} and I_2 with I_2^{11}, a no difference in the values indicating no deformation in the winding and a difference in the values indicating deformation in the winding, in which case carrying out the following steps :

(a) calculating the current deviation coefficient which is a non-limiting function of (I_1 - h^{11}) I (h ~ h^{11}) for identifying the section of the winding which has been deformed; comparing the calculated current deviation coefficient with the first fingerprint values of current deviation coefficients obtained in step A-2(iv) for locating the section of the winding which has been deformed, the current deviation coefficient being always negative for radial deformation of a section and being always positive for axial deformation of a section, the sign of the current deviation being an indicator of the type of deformation; the sign of current deviation coefficient for combined axial and radial deformations depending on the dominating type (axial or radial) of deformation and being located with the first set of finger print values obtained in step A-2(iv).

(b) calculating the difference between $I_\backslash$ and $I_\backslash''$ and between I_2 and I_2''; comparing the difference of $I\backslash —I\backslash^{11}$ with the corresponding second set of fingerprint values of $I_\backslash —1_\backslash^{1}$ obtained in step A-3 and also the difference of I_2 - Ii'' with the corresponding second set of fingerprint values of I_2 - 1_2^{1} obtained in step A-3 for the located section in step A-4(ii)(a) to give the extent of axial and radial deformation;

B) determining the change in the capacitance of the bushing of the transformer connected at the line end of the winding by

(i) measuring the terminal current values $I_\backslash^{1U}$ and $I_2'''as$ stated in step A-2(i) at the same high frequency voltage $V_\backslash$;

(ii) comparing the values of $I_\backslash$ with $I_\backslash^{1u}$ and I_2 with $I_2''^{1}$; a no difference in the values of I_2 and I_2^{1}'' and a difference between I_1 and $I_\backslash^{1}''$ indicating no deformation in the winding but a change in the bushing capacitance;

(iii) and if necessary determining the change in the bushing capacitance by finding out the difference between $I_\backslash$ and $I_\backslash^{1}''$ and dividing the difference by ω $V\backslash$ to give the change in capacitance of the bushing; and

C) determining the state of the insulation system of the transformer by detecting partial discharge pulses in the transformer winding by

(a)

(i) switching off the high frequency signal and measuring and analyzing the current variation of the partial discharge pulses seen at line terminal of the winding and at the other terminal of the winding to get signals I_1^{1111} and I_2'''' by digitally filtering signals with the band pass filter whose frequency band is the same as the frequency band in which transformer winding behaves as capacitive network as stated in A-2(i); and

(ii) determining the ratio of $I_1{}^{1111}II_2{}'' \, ''$ to give the location of partial discharge pulses, a ratio greater than one indicating the location of partial discharge towards the line end of the winding, a ratio near or close to one, indicating the location of partial discharge near or close to the center of the winding and a ratio less than one indicating the location of partial discharge towards the other end of the winding; and

(b)

by detecting change in the dielectric characteristics of the insulation system of the transformer by

(i) measuring the $\theta_1{}^{11}$ as described in step A-2(i) at the same high frequency voltage V_1; and

(ii) comparing the values of θ_1 obtained in step A-2(i) and Θ_1^{U} obtained in step C(b)(i), a substantial change in the values indicating change in the dielectric characteristics of the insulation system.

According to the invention there is also provided an on-line diagnostic method for health monitoring of a three phase delta connected transformer, the method comprising the following steps:

D) representing the three phase windings as Pl, P2 and P3 and further representing one of the phase windings P1 as a lumped parameter circuit and dividing the phase winding P1 into atleast two sections n;

E) generating a first set of fingerprint values by

(i) shorting under off-line condition both the ends of the phase winding P2 and connecting the shorted ends of the phase winding P2 to the ground terminal, measuring the injected high frequency terminal current $/_3$ at one end of the phase winding P1 when a constant sinusoidal voltage $V_\backslash$ is applied between the said one end of the phase winding P1 and the ground terminal and measuring the high frequency terminal current $/_4$ between the shorted ends of the phase windings P2 and the ground terminal and disconnecting the short circuited ends of the phase winding P2; the high frequency being selected only once in a band of frequencies at which the terminal impedance of the winding remains capacitive;

(ii) measuring the high frequency terminal current $l_\backslash$ at said one end of the phase winding P1 and current h at other end of the phase winding P1 when a constant sinusoidal voltage K_1 is applied through coupling capacitors between one ends of the phase windings Pl, P2 and P3 and ground terminal at the same high frequency, measuring the phase angle $\theta_\backslash$ between $I_\backslash$ and V_1, the injection of high frequency current along with power line current being carried out by employing known procedures of coupling and detecting such signals superimposed on power frequency voltage / current components;

(iii) calculating the sectional series capacitance (C_s) and the sectional ground capacitance (Q) of each of the sections n of the phase windings P1 using the values of $/_3$ and $/_4$ obtained in step E(i) and the value of bushing capacitance C_b provided by the transformer manufacturer as follows :

$$l = I_3 - \omega C_b V_x$$

$$N = \begin{bmatrix} \dfrac{\mathbf{L}}{I_4} & \dfrac{\omega V_1}{\boldsymbol{h}} \\ \dfrac{\left(I^2 - I_4^2\right)}{\omega V_\lambda I_A} & \dfrac{I}{I_4} \end{bmatrix}^{\frac{1}{n}}$$

$$C_\backslash = \frac{1}{2N(1,2)}$$

$$C_g = 2\,[C, JV(I, I) - C,]$$

where ω is selected high frequency in rad/sec,

n is number of sections,

N is 2 x 2 matrix obtained from measurements in step E(i) and N(l,l) and N(1,2) are the first and second element of row one of matrix N,

$V_\backslash$ is constant sinusoidal voltage applied in volts and

Z_3 and $/_4$ are two terminal current in amperes

(iv) simulating a range of deformations in each of the sections n of phase winding P 1 by changing the sectional ground capacitance C_g and sectional series capacitance C_s obtained in step E(iii) by predetermined percentages and generating simulated terminal current values $/_1{}^I$ and I_2^I under the same conditions and procedures corresponding to $/_1$ and I_2, respectively in step E(ii) for each change of the sectional ground capacitance and sectional series capacitance;

(v) calculating current deviation coefficient which is a non-limiting function of $(I_1 - I_1{}^I)I(JI\text{-}II^I)$ for each of the sections of the winding for each change of the sectional ground capacitance C_g obtained in step E(iii) and the sectional series capacitance C_s obtained in step E(iii); and forming a first set of finger print values using lookup table of the current deviation coefficients; and

(vi) calculating the difference^ - V) between $/_1$ obtained in step E(ii) and $/_1{}^I$ obtained in step E(iv) and also the difference $(I_2 - I_2{}^I)$ between I_2 obtained in step E(ii) and I_2^I obtained in step E(iv) for each of the sections of the phase winding P1 for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained in step E(iii) and forming a second set of fingerprint values using the lookup table of the current differences, the second set of fingerprint values indicating the extent of deformation of the deformed section; and

F. representing each of the phase windings P2 and P3 as a lumped parameter circuit and dividing each of the phase windings P2 and P3 into atleast two sections n and generating a first set of finger print values and a second set of finger print values for each of the remaining phase windings P2 and P3 as described in step (E), shorting of the ends of phase winding P3 is done for off-line measurement of phase winding P2 and shorting of the ends of phase winding Pl is done for off-line measurement of phase winding P3;

G) determining the location and extent of radial and/or axial deformation in the phase winding Pl by

(i) measuring the terminal current values $/_1{}^{I;}$ and h " as explained in step E(ii) at the same high frequency voltage F_1;

(ii) comparing the values of $I_\backslash$ with $/_1{}^{II}$ and $/_2$ with $/_2{}^{/I}$, a no difference in the values indicating no deformation in the winding and a difference in the values indicating deformation in the winding, in which case carrying out the following further steps :

(a) calculating the current deviation coefficient which is a non-limiting function of $\{I_\backslash$ - $h")$ I $\{h - h")$ for identifying the section of the winding which has been deformed; comparing the calculated current deviation coefficient with the first fingerprint values of current deviation coefficients obtained in step E(v) for locating the section of the winding which has been deformed, the current deviation coefficient being always positive for radial deformation of a section and being always negative for axial deformation of a section, the sign of the current deviation being an indicator of the type of deformation; the sign of current deviation coefficient for combined axial and radial deformations depending on the dominating type (axial or radial) of deformation and being located with the first of finger print values obtained in step E(v);

(b) calculating the difference between $I_\backslash$ and $I_\backslash$" and between $/_2$ and I_2" ; comparing the difference of $I_\backslash$ - $I_\backslash$" with the corresponding second set of fingerprint values of $I\backslash$ - $I\backslash^I$ obtained in step E(vi) and also the difference of $/_2$ - h " with the corresponding second set of fingerprint values of I_2 - h' obtained in step E(vi) for the located section in step G(ii)(a) to give the extent of deformation;

H) repeating the above procedure for determining the location and extent of radial and/or axial deformation in the other phase windings P2 and P3;

I) determining the change in the capacitance of the bushing of the transformer connected at the line end of each of the phase windings Pl, P2 and P3 by

(i) measuring the terminal current values $I_{\backslash}'''$ and h''^{1} as stated in step E(ii) at the same high frequency voltage $V_{\backslash}$;

(ii) comparing the values of $I_{\backslash}$ with $I_{\backslash}^{1}''$ and h with h^{1}''; a no difference in the values of $/_2$ and h''^{1} and a difference between $I_{\backslash}$ and $I_{\backslash}'^{n}$ indicating no deformation in the winding but a change in the bushing capacitance;

(iii) and if necessary determining the change in the bushing capacitance by finding out the difference between $I_{\backslash}$ and $I_{\backslash}^{1}''$ and dividing the difference by ω $V\backslash$ to give the change in capacitance of the bushing; and

J) determining the state of the insulation system of the transformer :

(a) by detecting partial discharge pulses in each of the phase windings Pl, P2 and P3 by

(i) switching off the high frequency signal and measuring and analyzing the current variation of the partial discharge pulses seen at line terminal of the phase winding and at the other terminal of the phase winding to get signals $I_{\backslash}''''$ and h'''' by digitally filtering signals with the band pass filter whose frequency band is the same as the frequency band in which transformer winding behaves as capacitive network as stated in step E(i); and

(ii) determining the ratio of I_1^{IIII}/I_2^{IIII} to give the location of partial discharge pulses, a ratio greater than one indicating the location of partial discharge towards the line end of the winding, a ratio near or close to one, indicating the location of partial discharge near or close to the center of the phase winding and a ratio less than one indicating the location of partial discharge towards the other end of the phase winding; and

(b) by detecting change in the dielectric characteristics of the insulation system of the transformer by

(i) measuring the θ_1'' as described in step E(ii) at the same high frequency voltage V_1; and

(ii) comparing the values of θ_1 in step E(ii) and θ_1'' in step J(b)(i), a substantial change in the values indicating change in the dielectric characteristics of the insulation system.

The following is a detailed description of the invention with reference to the accompanying drawings, in which:

Fig 1 is a lumped parameter circuit representation of a single phase transformer winding;

Fig 2 is a pi (Π) model representation of each section of the transformer winding of Fig 1 at the selected high frequency;

Fig 3 is a representation of the three phase windings of a three phase transformer connected in star configuration; and

Fig 4 is a representation of the three phase windings of a three phase transformer connected in delta configuration.

In Fig 1 of the accompanying drawings, the transformer winding is represented as a lumped parameter circuit and the winding is divided into different uniform sections n. Each section of the transformer winding comprises elements like series capacitance (C_s), self inductance *(L_n)*, mutual inductance *(Ly)*, / andy standing for 1 to n and ground capacitance *(C_g)*. The bushing capacitance Q, and the coupling capacitor C_c are also shown in Fig 1. $V_\backslash$ is the applied high frequency voltage. $I_\backslash$ is the high frequency current drawn from source, / is high frequency current going into the winding at one end of the winding, *h* is the high frequency current going out the winding to ground at other end of the winding. Each section of the winding is represented by a pi (IT) model at the selected high frequency as illustrated in Fig 2 of the accompanying drawings, in which two legs are given by $C_g l2$.

According to the method of the invention, deformation in the transformer winding of Figs 1 and 2 is determined by generating a first set of fingerprint values by

(i) measuring the high frequency terminal current $I_\backslash$ at one end of the winding when a constant sinusoidal voltage $V_\backslash$ is applied between one end of the winding and one ground terminal at a high frequency in a band of frequencies at which the terminal impedance of the winding remains capacitive, while keeping the other end of the winding and the other ground terminal connected; measuring the high frequency terminal current $/_2$ flowing from other end of the winding to the other ground terminal at the same high frequency, while keeping the same voltage *V* between one end of the winding and the one ground terminal and measuring the phase angle $\theta_\backslash$ between *I* and *V]*; wherein the application of high frequency voltage and detection of high frequency currents being carried out by employing known procedures of coupling and detecting such signals superimposed on power frequency voltage / current components;

ii) calculating the sectional series capacitance (C_s) and the sectional ground capacitance (C_g) of each of the different sections n of the winding using the values of I_1, I_2 and V_1 obtained above and the value of bushing capacitance C_b, provided by the transformer manufacturer as follows:

$$I = I_1 - \omega C_b V_1$$

$$N = \begin{bmatrix} \frac{I}{I_2} & \frac{\omega V_1}{I_2} \\ \frac{\left(I^2 - I_2^2\right)}{\omega V_1 I_2} & \frac{I}{I_2} \end{bmatrix}^{\frac{1}{n}}$$

$$C_s = \frac{1}{N(1,2)}$$

$$C_g = 2[C_s N(1,1) - C_s]$$

where ω is the selected high frequency in rad/sec,

n is number of sections,

N is 2 x 2 matrix obtained from measurements above and $N(1,1)$ and $N(1,2)$ are the first and second element of row one of matrix N,

V_1 is constant sinusoidal voltage applied in volts, and

I_1 and I_2 are two terminal currents in amperes

(iii) simulating a range of deformations in each of the sections of the winding by changing the sectional ground capacitance C_g and sectional series capacitance C_s obtained above by predetermined percentages and generating simulated terminal current values I_1' and I_2' under the same conditions and procedures corresponding to I_1 and I_2, respectively as above for each change of the sectional ground capacitance and sectional series capacitance;

(iv) calculating current deviation coefficient which is a non-limiting function of $(I_1 - I_1')/(I_2 - I_2')$ for each of the sections of the winding for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained above to form a first look up table of current deviation coefficients; and forming a first set of finger print values using the current deviation coefficients, the first set of finger print values indicating the location of the deformed section of the winding and the type of deformation; and

(v) generating a second set of finger print values by calculating the difference between $I_\backslash$ and $I_\backslash{}^I$ obtained above and between $/_2$ and $/_2{}^;$ obtained above for each of the sections of the winding for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained above; forming a second lookup table of differences and forming a second set of finger print values using the differences, the second set of fingerprint values indicating the extent of deformation of the deformed section.

The location and extent of radial or axial deformation or combination of both radial and axial deformation in the winding is determined by

(i) measuring the terminal current values $/_1{}^{II}$and h " as explained above at the same high frequency voltage F_1;

(ii) comparing the values of $I_\backslash$ with //' and $/_2$ with $/_2{}^{I/}$, a no difference in the values indicating no deformation in the winding and a difference in the values indicating deformation in the winding, in which case carrying out the following steps :

(a) calculating the current deviation coefficient which is a non-limiting function of *(I\ - h")* *I* $(I_2 - h")$ for identifying the section of the winding which has been deformed; comparing the calculated current deviation coefficient with the first fingerprint values of current deviation coefficients obtained above for locating the section of the winding which has been deformed, the current deviation coefficient being always negative for radial deformation of a section and being always positive for axial deformation of a section, the sign of the current deviation being an indicator of the type of deformation; the sign of current deviation coefficient for combined axial and radial deformations depending on the dominating type (axial or radial) of deformation and being located with the first set of finger print values; and

(b) calculating the difference between I_1 and I_1'' and between I_2 and I_2'' comparing the difference of $I_1 - I_1''$ with corresponding second set of fingerprint values of $I_1 - I_1'$ obtained above and also the difference of $I_2 - I_2''$ with the corresponding second set of fingerprint values of $I_2 - I_2'$ obtained above for the located section obtained above to give the extent of axial and radial deformation.

The change in the capacitance of the bushing of the transformer connected at the line end of the winding is determined by

(i) measuring the terminal current values I_1''' and I_2''' as stated above at the same high frequency voltage V_1

(ii) comparing the values of I_1 with I_1''' and I_2 with I_2'''; a no difference in the values of I_2 and I_2''' and a difference between I_1 and I_1''' indicating no deformation in the winding but a change in the bushing capacitance;

(iii) and if necessary determining the change in the bushing capacitance by finding out the difference between I_1 and I_1''' and dividing the difference by ωV_1 to give the change in capacitance of the bushing.

The state of the insulation system of the transformer is determined by detecting partial discharge pulses in the transformer winding by

(a)

(i) switching off the high frequency signal and measuring and analyzing the current variation of the partial discharge pulses seen at line terminal of the winding and at the other terminal of the winding to get signals $I_{\backslash}^{llu}$ and h''^{11} by digitally filtering signals with the band pass filter whose frequency band is the same as the frequency band in which transformer winding behaves as capacitive network as stated above; and

(ii) determining the ratio of $1_{1}^{I}''\,{}^{1}Ih''\,^{11}$ to give the location of partial discharge pulses, a ratio greater than one indicating the location of partial discharge towards the line end of the winding, a ratio near or close to one, indicating the location of partial discharge near or close to the center of the winding and a ratio less than one indicating the location of partial discharge towards the other end of the winding; and

(b)

by detecting change in the dielectric characteristics of the insulation system of the transformer by

(i) measuring the $\Theta_{\backslash}^{U}$ as described above at the same high frequency voltage $V\backslash$; and

(ii) comparing the values of $\theta_{\backslash}$ and $\theta_{\backslash}''$, substantial change in the values indicating change in the dielectric characteristics of the insulation system.

In the case of the three phase star connected windings of the transformer as illustrated in Fig 3 of the accompanying drawings, the various health factors of each of the phase windings are determined on-line as described above.

In the case of a three phase delta connected transformer of Fig 4 of the accompanying drawings, on-line measurement of health factors of the transformer according to the invention are carried out by

1) representing the three phase windings as Pl, P2 and P3 and further representing one of the phase windings PI as a lumped parameter circuit and dividing the phase winding Pl into atleast two sections $n\backslash$

2) generating a first set of fingerprint values by

(i) shorting under off-line condition both the ends of the phase winding P2 and connecting the shorted ends of the phase winding P2 to the ground terminal, measuring the injected high frequency terminal current $/_3$ at one end of the phase winding Pl when a constant sinusoidal voltage V_1 is applied between the said one end of the phase winding Pl and the ground terminal and measuring the high frequency terminal current $/_4$ between the shorted ends of the phase windings P2 and the ground terminal and disconnecting the short circuited ends of the phase winding P2; the high frequency is selected only once in a band of frequencies at which the terminal impedance of the winding remains capacitive;

(ii) measuring the high frequency terminal current $I_\backslash$ at said one end of the phase winding Pl and current $/_2$ at other end of the phase winding Pl when a constant sinusoidal voltage $V\backslash$ is applied through coupling capacitors between one ends of the phase windings Pl, P2 and P3 and ground terminal at the same high frequency, measuring the phase angle $\theta\backslash$ between $I\backslash$ and $V\backslash$, the injection of high frequency current along with power line current being carried out by employing known procedures of coupling and detecting such signals superimposed on power frequency voltage / current components;

(iii) calculating the sectional series capacitance (C_5) and the sectional ground capacitance (Q) of each of the sections n of the phase windings P1 using the values of $/_3$ and $/_4$ obtained above and the value of bushing capacitance C_b provided by the transformer manufactured as follows :

$$I = l_3 - \omega C_b V_1$$

$$N = \begin{bmatrix} \dfrac{I}{I_4} & \dfrac{\omega V_1}{I_4} \\ \dfrac{\left(I^2 - I_4^2\right)}{\omega V_1 I_4} & \dfrac{I}{I_4} \end{bmatrix}^{\frac{1}{n}}$$

$$C_s = \frac{I}{2N(1,2)}$$

$$C_g = 2[C_s N(\backslash,\backslash) - C_3]$$

where ω is selected high frequency in rad/sec,

n is number of sections,

N is 2 x 2 matrix obtained from measurements stated above and N(I,I) and N(1,2) are the first and second element of row one of matrix N,

V] is constant sinusoidal voltage applied in volts and

$/_3$ and U are two terminal current in amperes

(iv) simulating a range of deformations in each of the sections n of phase winding P1 by changing the sectional ground capacitance C_g and sectional series capacitance C_5 obtained above by predetermined percentages and generating simulated terminal current values $I\backslash^{l}$ and $/2^{l}$ under the same conditions and procedures corresponding to $I\backslash$ and h, respectively as stated above for each change of the sectional ground capacitance and sectional series capacitance.

(v) calculating current deviation coefficient which is a non-limiting function of *{I\-I\ ^{l})l{Ji−h ^{l}*) for each of the sections of the winding for each change of the sectional ground capacitance C_g obtained above and the sectional series capacitance C_s obtained above; and forming a first set of finger prints values using lookup table of the current deviation coefficients, and

(vi) calculating the difference^ - //) between I_1 obtained above and $/_1{}^1$ obtained above and also the difference $(I_2 - h')$ between $/_2$ obtained above and $I_2{}^1$ obtained above for each of the sections of the phase winding Pl for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained above, forming a second set of fingerprint values using the lookup table of the current differences, the second set of fingerprint values indicating the extent of deformation of the deformed section; and

3) representing each of the phase windings P2 and P3 as a lumped parameter circuit and dividing each of the phase windings P2 and P3 into atleast two sections *n* and generating a first set of finger print values and a second set of finger print values for each of the remaining phase windings P2 and P3 as described above, shorting of the ends of phase winding P3 is done for off-line measurement of phase winding P2 and shorting of the ends of phase winding Pl is done for off-line measurement of phase winding P3.

4) determining the location and extent of radial and/or axial deformation in the phase winding Pl by

(i) measuring the terminal current values I_1'' and h'' as explained above at the same high frequency voltage $V\backslash$;

(ii) comparing the values of I_1 with I_1'' and $/_2$ with h'', a no difference in the values indicating no deformation in the winding and a difference in the values indicating deformation in the winding, in which case carrying out the following further steps :

(a) calculating the current deviation coefficient which is a non-limiting function of $(/_1 - h^{11}) I (h \sim h'')$ for identifying the section of the winding which has been deformed; comparing the calculated current deviation coefficient with the first fingerprint values of current deviation coefficients obtained above for locating the section of the winding which has been deformed, the current deviation coefficient being always positive for radial deformation of a section and being always negative for axial deformation of a section, the sign of the current deviation being an indicator of the type of deformation; the sign of current deviation coefficient for combined axial and radial deformations depending on the dominating type (axial or radial) of deformation and being located with the first of finger print values obtained above;

(b) calculating the difference between $I_\backslash$ and $I_\backslash''$ and between $/_2$ and $/_2^{/I}$; comparing the difference of $1_\backslash - I_\backslash''$ with the corresponding second set of fingerprint values of $I\backslash - /_1^I$ obtained above and also the difference of $/_2 - h''$ with the corresponding second set of fingerprint values of $/_2 - h'$ obtained above for the located section to give the extent of deformation;

5) repeating the above procedure for determining the location and extent of radial and/or axial deformation in the other phase windings P2 and P3;

6) determining the change in the capacitance of the bushing of the transformer connected at the line end of each of the phase windings Pl, P2 and P3 by

(i) measuring the terminal current values $l_\backslash{}'^n$ and $/_2^{7//}$ as stated above at the same high frequency voltage $V_\backslash\backslash$

(ii) comparing the values of / i with I_1^{III} and $/_2$ with h " 1: a no difference in the values of $/_2$ and h " 1 and a difference between $I_\backslash$ and $I_\backslash^{I}$ " indicating no deformation in the winding but a change in the bushing capacitance;

(iii) and if necessary determining the change in the bushing capacitance by finding out the difference between $I\backslash$ and $I\backslash$" 1 and dividing the difference by ω $V_\backslash$ to give the change in capacitance of the bushing; and

7) determining the state of the insulation system of the transformer :

(a) by detecting partial discharge pulses in each of the phase windings Pl, P2 and P3 by

(i) switching off the high frequency signal and measuring and analyzing the current variation of the partial discharge pulses seen at line terminal of the phase winding and at the other terminal of the phase winding to get signals $l_\backslash^{UU}$ and h"" by digitally filtering signals with the band pass filter whose frequency band is the same as the frequency band in which transformer winding behaves as capacitive network as stated above; and

(ii) determining the ratio of $I_\backslash^{IIII}Ih^{IIII}$ to give the location of partial discharge pulses, a ratio greater than one indicating the location of partial discharge towards the line end of the winding, a ratio near or close to one, indicating the location of partial discharge near or close to the center of the phase winding and a ratio less than one indicating the location of partial discharge towards the other end of the phase winding; and

(b) by detecting change in the dielectric characteristics of the insulation system of the transformer by

(i) measuring the $\theta_\backslash$" as described above at the same high frequency voltage $V_\backslash$\ and

(ii) comparing the values of $\theta\backslash$ and θ_1^{II}, a substantial change in the values indicating change in the dielectric characteristics of the insulation system.

According to the invention, the on-line diagnostic method continuously monitors multiple health factors of the transformer in service condition without having to isolate the transformer from the power system in which it is connected so as to give a comprehensive health status of the transformer. It is accurate and reliable and effective in determining health factors of the transformer. It eliminates the down time required for the diagnosis of the health condition of the transformer. It helps to understand the dynamic behaviour of the transformer subjected to short circuit as the measurement is done on-line. It is also simple and easy to carry out and is economical and user friendly as it is based on a few terminal measurements and is deskilled as no expertise is required to deduce diagnostic conclusions.

The above embodiment of the invention is by way of example and should not be construed and understood to be limiting the scope of the invention. Several variations of the invention obvious to those skilled in the art and falling within the scope of the invention are possible. The transformer winding may be divided into non-uniform sections. The deformations in the transformer winding may be determined for multiple sections of the winding. The location and extent of deformation may be determined for any current carrying coil besides transformer winding. The on-line method also can be used to measure or monitor health factors of both the HV and LV windings of the transformer simultaneously. Such variations of the invention are obvious to those skilled in the art and are to be construed and understood to be within the scope of the invention.

CLAIMS:

1) An on-line diagnostic method for health monitoring of a single phase transformer or a three phase star connected transformer, the method comprising the following steps :

A) determining deformations in the transformer winding by

A-I) representing the transformer winding as a lumped parameter circuit and dividing the winding into at least two sections *n;*

A-2) generating a first set of fingerprint values by

(i) measuring the high frequency terminal current I_1 at one end of the winding when a constant sinusoidal voltage V_1 is applied between one end of the winding and one ground terminal at a high frequency in a band of frequencies at which the terminal impedance of the winding remains capacitive, while keeping the other end of the winding and the other ground terminal connected; measuring the high frequency terminal current I_2 flowing from other end of the winding to the other ground terminal at the same high frequency, while keeping the same voltage V_1 between one end of the winding and the one ground terminal; and measuring the phase angle θ_1 between I_1 and V_1, the application of high frequency voltage and detection of high frequency currents being carried out by employing known procedures of coupling and detecting such signals superimposed on power frequency voltage / current components;

ii) calculating the sectional series capacitance (C_s) and the sectional ground capacitance (C_g) of each of the different sections n of the winding using the values of I_1, I_2 and V_1 obtained in step A-2(i) and the value of bushing capacitance C_b provided by the transformer manufacturer as follows:

$$I = I_1 - \omega C_b V_1$$

$$N = \begin{bmatrix} \frac{I}{I_2} & \frac{\omega V_1}{I_2} \\ \frac{(I^2 - I_2^2)}{\omega V_1 I_2} & \frac{I}{I_2} \end{bmatrix}^{\frac{1}{n}}$$

$$C_s = \frac{1}{N(1,2)}$$

$$C_g = 2\left[C_s N(1,1) - C_s\right]$$

where ω is the selected high frequency in rad/sec,

n is number of sections,

N is 2 x 2 matrix obtained from measurements in step A-2(i) and

$N(1,1)$ and $N(1,2)$ are the first and second element of row one of matrix N,

V_1 is constant sinusoidal voltage applied in volts, and

I_1 and I_2 are two terminal currents in amperes

(iii) simulating a range of deformations in each of the sections of the winding by changing the sectional ground capacitance C_g and sectional series capacitance C_s obtained in step A-2(ii) by predetermined percentages and generating simulated terminal current values I_1' and I_2' under the same conditions and procedures corresponding to I_1 and I_2, respectively in step A-2(i) for each change of the sectional ground capacitance and sectional series capacitance;

(iv) calculating current deviation coefficient which is a non-limiting function of $(I_1 - I_1')/(I_2 - I_2')$ for each of the sections of the winding for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained in step A-2(iii) to form a first look up table of current deviation coefficients; and forming a first set of finger print values using the current deviation coefficients, the first set of finger print values indicating the location of the deformed section of the winding and the type of deformation;

A-3) generating a second set of finger print values by calculating the difference between $/_1$ obtained in step A-2(i) and $/_1{}^I$ obtained in step A-2(iii) and between I_2 obtained in step A-2 (i) and $I_2{}^I$ obtained in step A-2 (iii) for each of the sections of the winding for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained in step A-2 (iii); forming a second lookup table of differences and forming a second set of finger print values using the differences, the second set of fingerprint values indicating the extent of deformation of the deformed section; and

A-4) determining the location and extent of radial or axial deformation or combination of both radial and axial deformation in the winding by

(i) measuring the terminal current values $I_1{}^{II}$ and h'' as explained in step A-2(i) at the same high frequency voltage $V_\backslash$;

(ii) comparing the values of $1_\backslash$ with I_1'' and $/_2$ with h'', a no difference in the values indicating no deformation in the winding and a difference in the values indicating deformation in the winding, in which case carrying out the following steps :

(a) calculating the current deviation coefficient which is a non-limiting function of (Yi - *h") I (h ~ h")* for identifying the section of the winding which has been deformed; comparing the calculated current deviation coefficient with the first fingerprint values of current deviation coefficients obtained in step A-2(iv) for locating the section of the winding which has been deformed, the current deviation coefficient being always negative for radial deformation of a section and being always positive for axial deformation of a section, the sign of the current deviation being an indicator of the type of deformation; the sign of current deviation coefficient for combined axial and radial deformations depending on the dominating type (axial or radial) of deformation and being located with the first set of finger print values obtained in step A-2(iv).

(b) calculating the difference between I_1 and $I_\backslash''$ and between $/_2$ and $/_2^{/1}$; comparing the difference of $I_\backslash - I_\backslash''$ with the corresponding second set of fingerprint values of $I_\backslash - /_1^{I}$ obtained in step A-3 and also the difference of $/_2 - h''$ with the corresponding second set of fingerprint values $oih - h'$ obtained in step A-3 for the located section in step A-4(ii)(a) to give the extent of axial and radial deformation;

B) determining the change in the capacitance of the bushing of the transformer connected at the line end of the winding by

(i) measuring the terminal current values $I_\backslash^{I}{}''$ and $I_2^{II}{}'$ as, stated in step A-2(i) at the same high frequency voltage $V_\backslash$;

(ii) comparing the values of $1_\backslash$ with $I_1''^{1}$ and h with h'''; a no difference in the values of h and h''^{1} and a difference between $I_\backslash$ and $1_\backslash^{IU}$ indicating no deformation in the winding but a change in the bushing capacitance;

(iii) and if necessary determining the change in the bushing capacitance by finding out the difference between $I_\backslash$ and $I_\backslash^{IU}$ and dividing the difference by ω $V_\backslash$ to give the change in capacitance of the bushing; and

C) determining the state of the insulation system of the transformer by detecting partial discharge pulses in the transformer winding by

(a)

(i) switching off the high frequency signal and measuring and analyzing the current variation of the partial discharge pulses seen at line terminal of the winding and at the other terminal of the winding to get signals $I_\backslash^{U}{}''$ and $h'^{1}{}''$ by digitally filtering signals with the band pass filter whose frequency band is the same as the frequency band in which transformer winding behaves as capacitive network as stated in A-2(i); and

(ii) determining the ratio of $I_\backslash^{U''} II_2^{I''1}$ to give the location of partial discharge pulses, a ratio greater than one indicating the location of partial discharge towards the line end of the winding, a ratio near or close to one, indicating the location of partial discharge near or close to the center of the winding and a ratio less than one indicating the location of partial discharge towards the other end of the winding; and

(b)

by detecting change in the dielectric characteristics of the insulation system of the transformer by

(i) measuring the $\theta_\backslash''$ as described in step A-2(i) at the same high frequency voltage $V\backslash\backslash$ and

(ii) comparing the values of $\theta_\backslash$ obtained in step A-2(i) and $\theta\backslash''$ obtained in step C(b)(i), a substantial change in the values indicating change in the dielectric characteristics of the insulation system.

2. An on-line diagnostic method for health monitoring of a three phase delta connected transformer, the method comprising the following steps :

D) representing the three phase windings as Pl, P2 and P3 and further representing one of the phase windings Pl as a lumped parameter circuit and dividing the phase winding Pl into atleast two sections n;

E) generating a first set of fingerprint values by

(i) shorting under off-line condition both the ends of the phase winding P2 and connecting the shorted ends of the phase winding P2 to the ground terminal, measuring the injected high frequency terminal current $/_3$ at one end of the phase winding P1 when a constant sinusoidal voltage $V_\backslash$ is applied between the said one end of the phase winding P1 and the ground terminal and measuring the high frequency terminal current $/_4$ between the shorted ends of the phase windings P2 and the ground terminal and disconnecting the short circuited ends of the phase winding P2; the high frequency being selected only once in a band of frequencies at which the terminal impedance of the winding remains capacitive;

(ii) measuring the high frequency terminal current $I\backslash$ at said one end of the phase winding P1 and current $/_2$ at other end of the phase winding P1 when a constant sinusoidal voltage $V\backslash$ is applied through coupling capacitors between one ends of the phase windings Pl, P2 and P3 and ground terminal at the same high frequency, measuring the phase angle $\theta_\backslash$ between $/_1$ and $V\backslash$, the injection of high frequency current along with power line current being carried out by employing known procedures of coupling and detecting such signals superimposed on power frequency voltage / current components;

(iii) calculating the sectional series capacitance (C_s) and the sectional ground capacitance (C_g) of each of the sections n of the phase windings P1 using the values of $/_3$ and $/_4$ obtained in step E(i) and the value of bushing capacitance C_b provided by the transformer manufacturer as follows :

$$I = I_3 - \omega C_6 V_1$$

$$N = \begin{bmatrix} \frac{L}{I_4} & \frac{\omega V_1 L}{I_4} \\ \frac{\left(I^2 - I_4^2\right)}{\omega V_x I_4} & \frac{I}{I_4} \end{bmatrix}^{\frac{1}{n}}$$

$$C_s = \frac{1}{2N(1,2)}$$

$$C_g = 2[QN(I,I) - Cj$$

where ω is selected high frequency in rad/sec,

n is number of sections,

N is 2 x 2 matrix obtained from measurements in step E(i) and $N(1,1)$ and $N(1,2)$ are the first and second element of row one of matrix N,

V_1 is constant sinusoidal voltage applied in volts and

I_3 and I_4 are two terminal current in amperes

(iv) simulating a range of deformations in each of the sections n of phase winding P1 by changing the sectional ground capacitance C_g and sectional series capacitance C_s obtained in step E(iii) by predetermined percentages and generating simulated terminal current values I_1' and I_2' under the same conditions and procedures corresponding to I_1 and I_2, respectively in step E(ii) for each change of the sectional ground capacitance and sectional series capacitance;

(v) calculating current deviation coefficient which is a non-limiting function of $(I_1-I_1')/(I_2-I_2')$ for each of the sections of the winding for each change of the sectional ground capacitance C_g obtained in step E(iii) and the sectional series capacitance C_s obtained in step E(iii); and forming a first set of finger print values using lookup table of the current deviation coefficients; and

(vi) calculating the difference $(I_1 - I_1')$ between I_1 obtained in step E(ii) and I_1' obtained in step E(iv) and also the difference $(I_2 - I_2')$ between I_2 obtained in step E(ii) and I_2' obtained in step E(iv) for each of the sections of the phase winding P1 for each change of the sectional ground capacitance C_g and the sectional series capacitance C_s obtained in step E(iii) and forming a second set of fingerprint values using the lookup table of the current differences, the second set of fingerprint values indicating the extent of deformation of the deformed section; and

F. representing each of the phase windings P2 and P3 as a lumped parameter circuit and dividing each of the phase windings P2 and P3 into atleast two sections n and generating a first set of finger print values and a second set of finger print values for each of the remaining phase windings P2 and P3 as described in step (E), shorting of the ends of phase winding P3 is done for off-line measurement of phase winding P2 and shorting of the ends of phase winding P1 is done for off-line measurement of phase winding P3;

G) determining the location and extent of radial and/or axial deformation in the phase winding P1 by

(i) measuring the terminal current values $I_\backslash''$ and h'' as explained in step E(ii) at the same high frequency voltage $V_\backslash \backslash$

(ii) comparing the values of $l_\backslash$ with $I_\backslash''$ and $/_2$ with $/_2{}^{/y}$, a no difference in the values indicating no deformation in the winding and a difference in the values indicating deformation in the winding, in which case carrying out the following further steps :

(a) calculating the current deviation coefficient which is a non-limiting function of $(1\backslash - h'^1) I (h \sim h'')$ for identifying the section of the winding which has been deformed; comparing the calculated current deviation coefficient with the first fingerprint values of current deviation coefficients obtained in step E(v) for locating the section of the winding which has been deformed, the current deviation coefficient being always positive for radial deformation of a section and being always negative for axial deformation of a section, the sign of the current deviation being an indicator of the type of deformation; the sign of current deviation coefficient for combined axial and radial deformations depending on the dominating type (axial or radial) of deformation and being located with the first of finger print values obtained in step E(v);

(b) calculating the difference between $I_\backslash$ and $I_\backslash''$ and between $/_2$ and $I_2{}^{l'}$; comparing the difference of $I_\backslash - I_1{}^{ll}$ with the corresponding second set of fingerprint values of $I\backslash - I_1{}^{l}$ obtained in step E(vi) and also the difference of $/_2 - h''$ with the corresponding second set of fingerprint values of $/_2$ - h' obtained in step E(vi) for the located section in step G(ii)(a) to give the extent of deformation;

H) repeating the above procedure for determining the location and extent of radial and/or axial deformation in the other phase windings P2 and P3;

I) determining the change in the capacitance of the bushing of the transformer connected at the line end of each of the phase windings Pl, P2 and P3 by

(i) measuring the terminal current values $I_{\backslash}^{I}{}''$ and h''' as stated in step E(ii) at the same high frequency voltage V_1;

(ii) comparing the values of $l\backslash$ with I_1^{III} and h with h'''; a no difference in the values of $/_2$ and $/_2^{//;}$ and a difference between I_1 and $I_{\backslash}^{1U}$ indicating no deformation in the winding but a change in the bushing capacitance;

(iii) and if necessary determining the change in the bushing capacitance by finding out the difference between $I_{\backslash}$ and $I_{\backslash}^{IU}$ and dividing the difference by ω $V_{\backslash}$ to give the change in capacitance of the bushing; and

J) determining the state of the insulation system of the transformer :

(a) by detecting partial discharge pulses in each of the phase windings Pl, P2 and P3 by

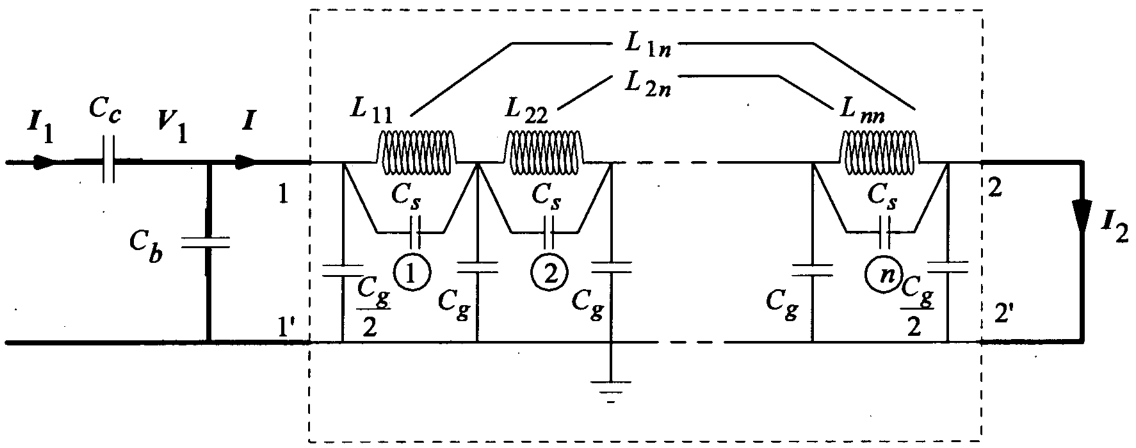
(i) switching off the high frequency signal and measuring and analyzing the current variation of the partial discharge pulses seen at line terminal of the phase winding and at the other terminal of the phase winding to get signals $I_{\backslash}{}''^{u}$ and $Ii^{Il}{}''$ by digitally filtering signals with the band pass filter whose frequency band is the same as the frequency band in which transformer winding behaves as capacitive network as stated in step E(i); and

(ii) determining the ratio of $I_1{}^{1}{}^{111}II_2{}'' ''$ to give the location of partial discharge pulses, a ratio greater than one indicating the location of partial discharge towards the line end of the winding, a ratio near or close to one, indicating the location of partial discharge near or close to the center of the phase winding and a ratio less than one indicating the location of partial discharge towards the other end of the phase winding; and

(b) by detecting change in the dielectric characteristics of the insulation system of the transformer by

(i) measuring the $\theta_\backslash''$ as described in step E(ii) at the same high frequency voltage $V\backslash\backslash$ and

(ii) comparing the values of $\theta_\backslash$ in step E(ii) and $\theta_\backslash''$ in step J(b)(i), a substantial change in the values indicating change in the dielectric characteristics of the insulation system.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L_{2n}
L_{11}
L_{22}
L_{nn}
I_1
C_c
V_1
I
C_b
1
1'
C_s
C_s
C_s
1
2
n
$\frac{C_g}{2}$
C_g
C_g
C_g
$\frac{C_g}{2}$
2
2'
I_2

Fig 1

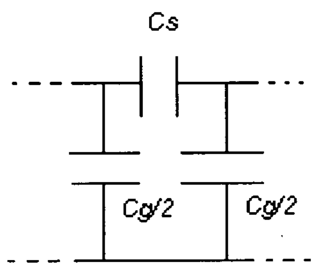
Cs
Cg/2
Cg/2

Fig 2

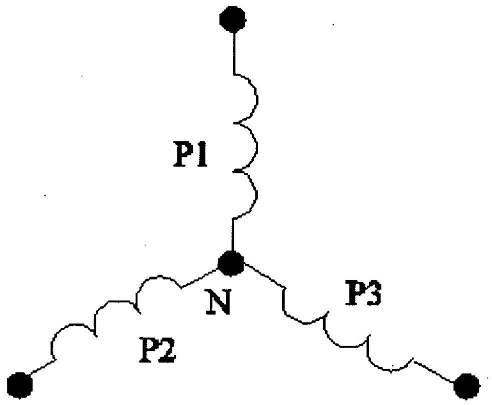

Fig 3

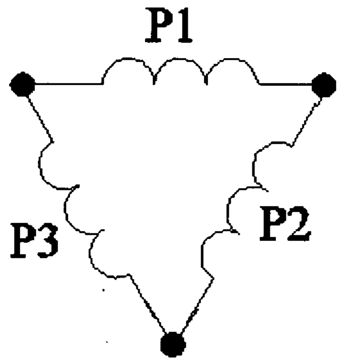

Fig 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IN2010/000474

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R31/06 G01R31/34
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. RELDS SEARCHEO

Minimum documentation searched (classification system followed by classification symbols)
GOIR

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal , WPI Data

C DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropnate, of the relevant passages	Relevant to claim No
A	WO 2009/069145 A2 (INDIAN INST OF TECHNOLOGY BOMB [IN]; MADHUKAR JOSHI PRASAD [IN]; VYANK) 4 June 2009 (2009-06-04) page 1, line 6 - page 2, line 20; claims 1,5,9 -----	1,2

-/--

[X] Further documents are listed in the continuation of Box C

[X] See patent family annex

* Special categoπes of cited documents

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L' document which may throw doubts on pnoπty claιm(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use exhibition or other means

"P" document published prior to the international filing date but later than the pnoπty date claimed

"T" later document published after the international filing date or pnoπty date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such docu¬ ments, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 December 2010	04/01/2011

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