Different Types of Winding Fault Analysis in Power Transformers

Rashed M. Marimi & Najeb A Elgeme
Dept. of Electrical and Electronic Engineering, faculty of Engineering
Zawia University

Abstract:

The power transformer is an essential piece of equipment for the effective transmission of electrical energy in transmission and distribution networks. Therefore, transformer failure is an important issue for the electrical industry sector. Transformer failure may occur for various reasons. Heavy usage and ageing are common factors that lead to transformer malfunction and may account for major maintenance costs. An appropriate monitoring method must therefore be implemented in the system to improve network reliability and avoid further maintenance costs. In this paper is proposed a new approach for *detecting and distinguishing internal faults within power transformers by using a locus characteristic algorithm. This locus of a transformer could be formed by plotting the differential voltage input and output against input current on the source side. This locus would be represented in an image which could then be analyzed using the image processing toolbox from MATLAB developed software. Importantly, this new technique uses an online monitoring, detection method which could monitor the transformer's condition while it is operating. This technique is an online monitoring, testing method that improves upon the current out-dated, offline testing methods such as the Frequency Response Analysis (FRA) and other uncommon online testing methods.The Frequency Response and Polar Coordinate methods will also be discussed in comparison with both MATLAB and power system simulation (PSIM) techniques.*

KEY WORDS: *Power Transformer, Condition Monitoring, Winding Displacement and Deformation, Forced Buckling, Locus, Polar coordinates, Turn to Turn Faults, Frequency Response Analyses (FRA).*

1.Introduction

In the contemporary age of technological advancement it has become a challenge for many nations to build a healthy economy in a way that is environmentally friendly and sustainable. The earth's population is ballooning and the increased reliance on electrical energy is increasing exponentially. The modern production of electricity still encompasses the traditional method of burning fossil fuels; however, nuclear and renewable energy production is on the rise. The former method is largely responsible for contributing to the negative phenomenon of global warming. This great quandary means that innovative methods are required to transform the entire industry to allow for a prosperous and green future. We have already witnessed huge policy changes at the federal government level in some nations. The Australian Prime Minister recently introduced a tax on carbon in an attempt to combat the high levels of carbon emissions [1, 2].

Another area of considerable concern is the power transformer's impact upon the transmission and distribution system. Electricity is produced at the power plant then subsequently transmitted and distributed across the network to end-users. Due to the varying degrees of voltage, it is necessary to use a power transformer to ensure the correct voltage levels are obtained. As stated earlier, the use of electricity has skyrocketed and therefore transmission lines are being constructed at a rapid rate, ultimately leading to an increase in the quantity of transformers required. This excessive loading will increase the probability of malfunctions, so it must be quickly rectified in order to restore the uninterrupted flow of electricity.

Without any visible signs to suggest an issue, power transformer faults may strike unexpectedly and cause major interruptions to the electrical network that links suppliers and consumers. Undoubtedly this leads to unhappy and frustrated consumers, which in turn leads to reduced revenue, as was the case with Western Power - the largest power company in Western Australia. It is therefore crucial to have a sound fault monitoring technique that results in the early detection and correction of transformer faults.

Transformer faults are currently identified via offline testing. This process involves separating the transformers from their circuits and conducting various tests to determine the specific nature of the faults. This is an inefficient process that should be overhauled by online testing.

The newly proposed technique works without the need to remove the transformers and would allow for real-time monitoring and testing, both of which would save substantial time and maintenance costs. Thus, this paper introduces a new approach for detecting and distinguishing internal faults within power transformers by using a locus characteristic algorithm and FRA method. This locus of a transformer could be formed by plotting the differential voltage input and output against input current on the source side. This locus would be represented in an image which could then be analyzed using the image processing toolbox from MATLAB software. Importantly, this new technique uses an online monitoring, detection method which could monitor the transformer's condition while it is operating.

2.Importance of Power Transformer Maintenance

Transformers are an integral part of electrical networks and help manage vital and substantial loads. They are used throughout copious industries and utilities with optimal reliability and a lifespan of 20 to 25 years. They are costly to buy and maintain, hence it is of pivotal importance to ensure they are looked after during operation.

With no sign of slowing down, technological advancement in the electrical industry continues to drive both corporate and consumer demand. There is a constant risk of overload and therefore it is important to explore ways in which the network capacity may be increased to accommodate a larger quantity of transformers.

Defective transformers must be swiftly dealt with before they cause severe damage, which may include fire hazards and explosions that are injurious and potentially fatal to personnel. Furthermore, the costly loss of productivity is another reason to ensure that all measures are put in place to prevent this from happening. According to some estimates [3], "The repair and replacement of a 350/138 KV transformer normally requires about 10 - 15 months. If a spare is available, the time needed for replacement of a failed unit is in the range of 10 - 12 weeks." A key measure is the real-time monitoring of transformers.

Winding deformation accounts for approximately one quarter of all transformer faults, and may result in overheating, ruptured or degraded insulation and clamping pressure [4].

Brand new transformers harbor a higher resistance to potential faults caused by short-circuiting. The strength of insulation degrades with age and the transformer becomes more susceptible to failures sparked by short-circuiting, lightning strikes and switching transients. As mentioned earlier, constantly monitoring a transformer's condition is essential for detecting issues that may lead to larger concerns down the track.

In regards to increased temperature abnormalities, these must be identified early to avoid negative outcomes, including a reduction in the transformer's carrying capacity, modification of the insulation material properties that may cause dislodged windings, and reduced longevity.

3. Frequency Response Analysis

Frequency Response Analysis (FRA) is a technique used to monitor the condition of high-priced power equipment. The FRA is used to measure the passive element (RLC) frequency response; for example, the transformer winding impedance over a large range of frequencies. This test is primarily designed in order to diagnose transformer incipient faults. The results obtained are matched against a reference data set and differences can be used to determine the type of fault and its location [5,6].

The FRA is a new and sound technique that boasts several analytical methods that are capable of identifying both minor and major faults. Mechanical winding damage is often difficult to detect with other methods, but not so with the FRA. The frequency behavior of RLC circuits assists with the description of internal transformer components [5]. The most frequent and successful way of running the FRA is known as sweep frequency response analysis. This method involves energizing the transformer via low input voltage; the frequency is swept. In other words, it changes from an extremely low to extremely high frequency [7]. The output response of varying frequencies is related to the resonance. Resonance change occurs because of the physical winding change that in turn causes a change in the inductance or capacitance. As the frequency increases the impedance of the inductors and capacitors also begins to change. [8, 9].

FRA testing is comprised of two key techniques. The first and most preferred technique involves comparing is a V_{out}/V_{in} (in DB scale) signature graph and Frequency (in Log Scale) of a healthy transformer with faulty transformer graphs. The second technique compares a $[V_{in}/I_{in}]$ (in DB Scale) signature graph vs. Frequency (In Log Scale) of a healthy transformer with faulty transformer graphs. A comparison of two different frequency responses is shown in the example below. The lighter line illustrates the fault measurement, whereas the darker line represents a healthy transformer reference measurement.

The research technique relies on the locus diagram construction relating the input current of transformer on x-axis and the input Vs output voltages of the particular on y-axis, and can be derived using phasor diagram and the single phase transformer equivalent circuit as shown in figure (1).

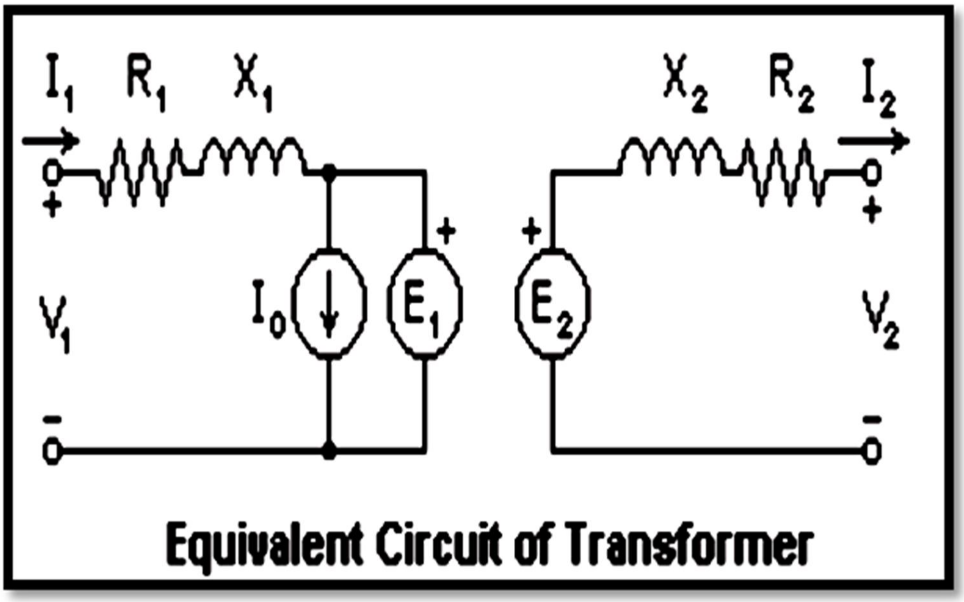

Fig .1: Equivalent Circuit of Transformer [10].

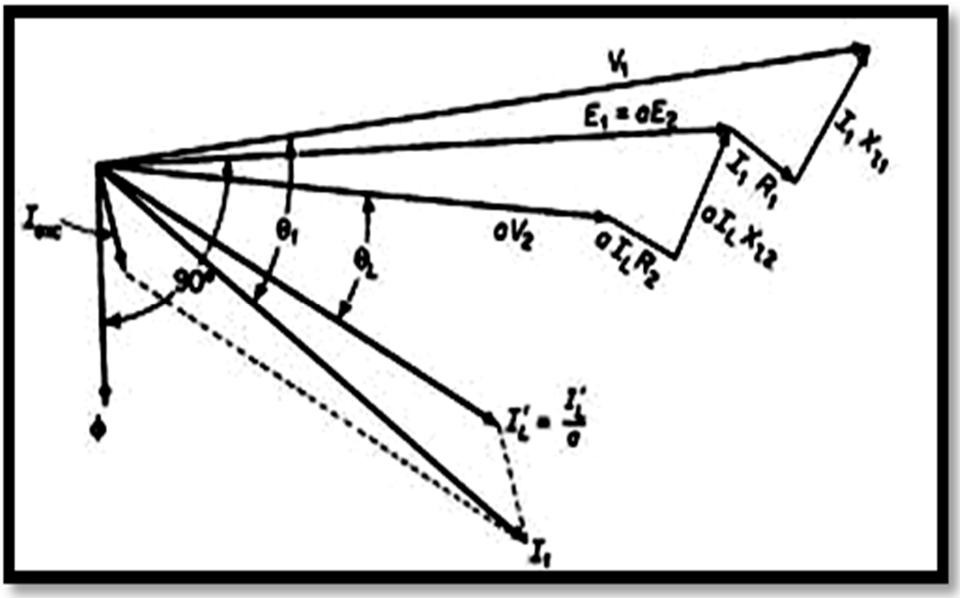

Fig .2: Phasor Diagram of the Transformer [10].

Thus, the following equations are derived by the figure (2)shown above,

$$(2V_m \cos\gamma)^2 * (x)^2 + 4V_m I_{m1} \cos\gamma * \sin\left(\frac{\gamma}{2} + \theta_1\right) * xy + (I_m^2 y^2) + \left(2V_m I_{m1} \cos\gamma * \sin\left(\frac{\gamma}{2} + \theta_2\right)^2\right) - ((2V_m I_{m1} \cos\gamma)^2) \quad (1)$$

Let,

$$A = (2V_m I_{m1} \cos\gamma)^2$$
$$B = 4V_m I_{m1} \cos\gamma$$
$$C = I_m^2$$
$$D = \left(2V_m I_{m1} \cos\gamma * \sin\left(\frac{\gamma}{2} + \theta_1\right)^2\right) - ((2V_m I_{m1} \cos\gamma)^2)$$

Thus,

$$B^2 - 4AC < 0$$
$$B^2 - 4AC = 16 * I_m^2 * V_m^2 \left[Cos^2(\gamma) Sin^2\left(\frac{\gamma}{2} + \phi\right) - Cos^2(\gamma)\right] \quad (2)$$

The equation (2) shows the negative term and represent an ellipse by Cartesian relationship between (V1-V2) and Iin. The measurement at a particular time is to calculate the point on the ΔV- Iinlocus at a 0.85 lagging power factor.

4.Transformer Model

Two disks of the distributed transformer model equivalent circuit proposed in this paper are shown in Figure (3) shown below.

A more advanced version of the RLC ladder network transformer model was concocted by academia and is displayed for the reader below. Variants of this model have been utilized in [11-12].

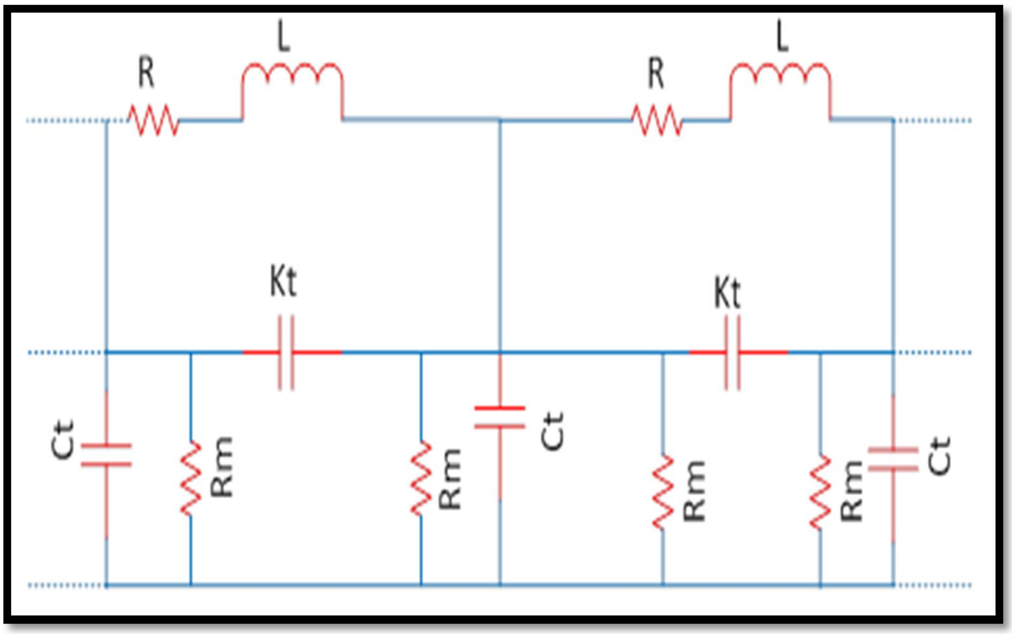

Fig .3: Academia's Distributed Parameter Transformer Model [8].

Where,R- Series Resistance due to DC and eddy current losses = 20Ω, L- Self and Mutual Inductance Lumped = 13.65mH, Ct- Shunt Capacitance from Element to Ground = 462pF, Kt- Series Capacitance along the, Element itself = 47.62pF, R_m- Dielectric losses to the ground = 210*1012Ω.

The circuits for FRA testing and the technique introduced in this paper have been deduced from a transformer model concocted by past academia [8]. PSIM software was utilized in order to simulate the circuit diagrams. A 102 disks of the model consisted of the high voltage (HV) and low voltage (LV) windings, and each one includes series inductance (L) and resistance (R) shunted by a capacitor and conductance. A dielectric conductance shunts the capacitance between high voltage winding and low voltage winding. The LV winding and earthed core has dielectric insulation. The dielectric insulation between HV winding and the earthed tank are simulated by a capacitance and dielectric conductance. Table 1 concludes model of the transformer and the specific effects mechanical faults.

5. Simulation Results

Figure 4 shows the model which consists of 102 disks (three turns per disc) using PSIM software for the simulation. The low amplitude of ac, 50 Hz sources energize the model the time step of 2300 µs record instantaneous values of v1, v2 and Iin. The transformer impedance will vary and this changes the transformer experiences ΔV-Iinlocus diagram that happens when the transformer experiences results in deformation of the windings. A ΔV- Iinlocus of a healthy transformer can be constructed and is considered as a fingerprint of this transformer.

The figure (4) and figure (5) show the simulation of different load levels at a constant power factor. Noting that, the increasing of load level of about 95% increment will not affect the locus.

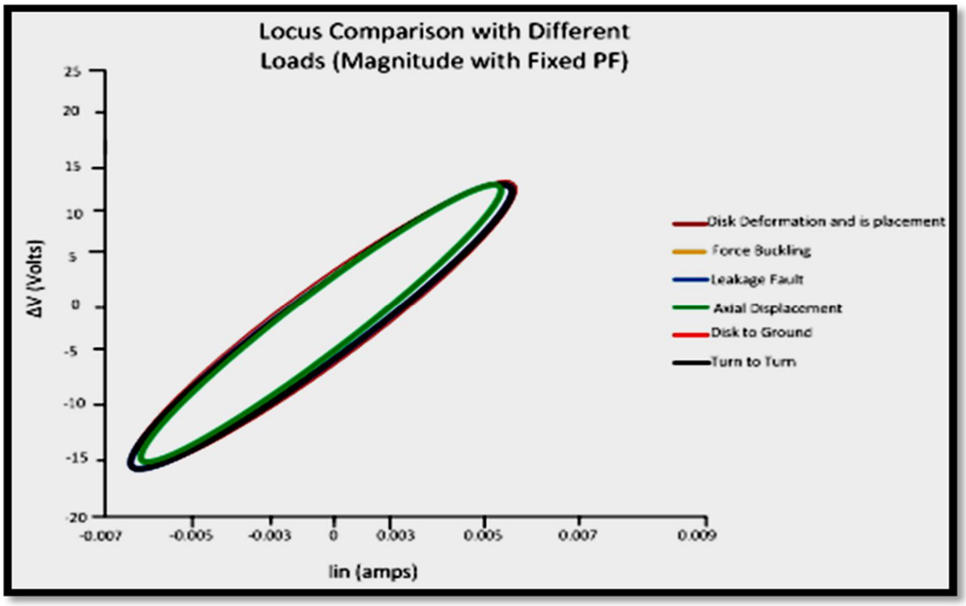

Fig. 4 Impact of load magnitude on the propose locus.

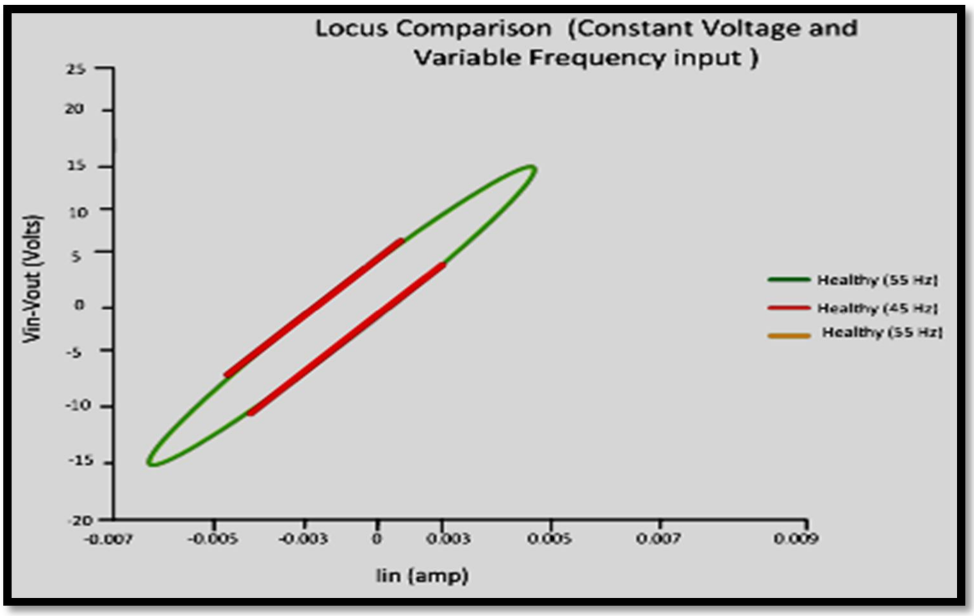

Fig .5: Locus Comparison of Varying Frequency Input (55Hz, 45Hz, 55Hz) with Constant Voltage.

The figure above shows the locus comparison of varying frequency input with a constant voltage. From the figure, the area of the locus increased with increasing frequency and vice versa.When there is a significant change in load level as evidenced in Figure (5), the effect of load magnitude on the proposed locus will take place as the load magnitude is increased to 230 Ω and the entire locus area is reduced at this level. Therefore, in all studied cases all loci have the same common major axis and same centroid.

6. Fault Analysis

The modeling and simulation are applied in different mechanical faults. The comparison and plotting are done between the corresponding ΔV- Iinloci and the healthy locus. The problem statement is achieved by comparing the healthy transformer fingerprint and the faulty one to identify any differences and to determine the possible fault type.

6.1 Short Circuit Load And Open Circuit Load

75% of transformers breakdown have been attributed to inter faults [13,14]. Different number of disks is short circuited to find its effect on the ΔV- Iinlocus. A 23% and 8% of a locus for faulty disks compared to the healthy locus as shown in figure (6) and figure (7). The figure observes that as the locus rotates in clockwise and its area increases, the amount of faulty disks increase.

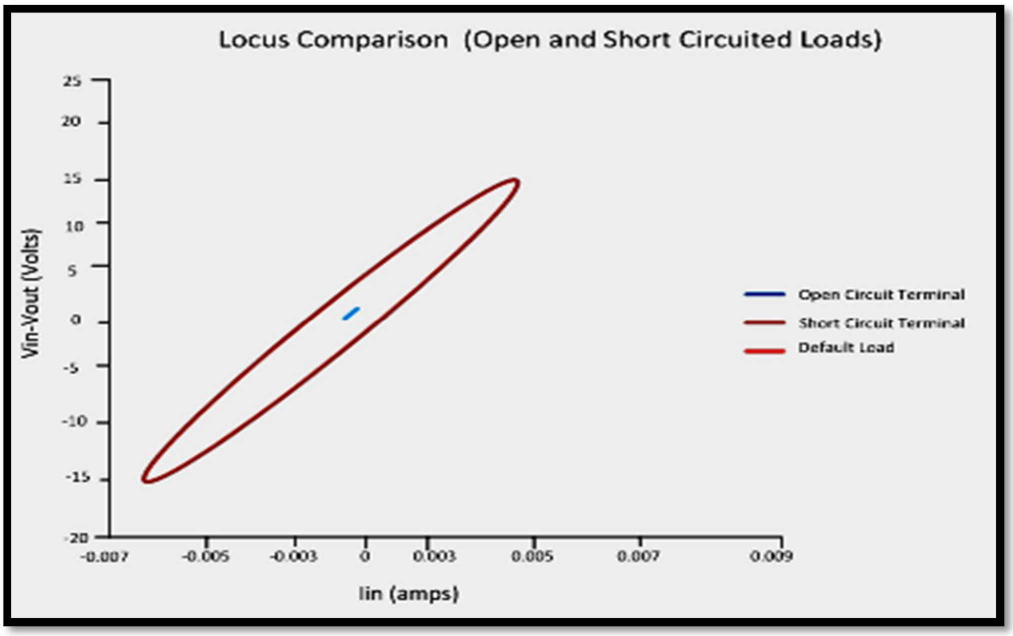

Fig .6: Locus Comparison between Short Circuited and Open Circuited Load.

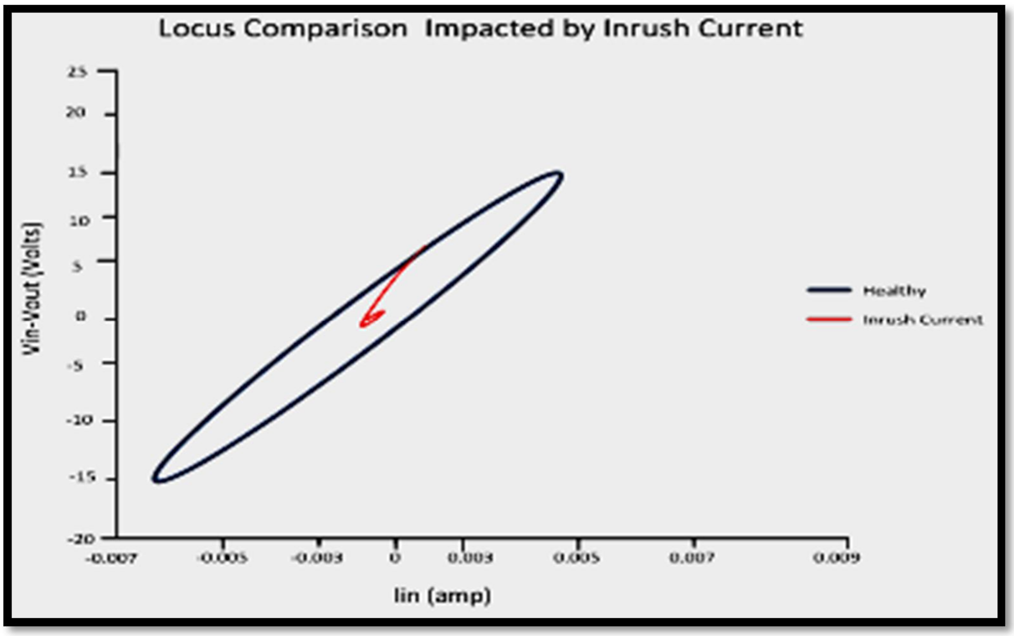

Fig .7: The Impact of Inrush Current on the Locus.

The figure above shows the locus comparison for a healthy default load and inrush current.

6.2 Axial Displacement

High short-circuit currents are the primary cause of axial displacements concerning transforming windings. The winding displacement is a mechanical fault which may result in the unwanted outage of a transformer. In other words, it may be described as the high voltage winding movement which is comparable to low voltage winding. The windings shift axially; however, the distance between them does not change. The axial movements accelerate the short circuit forces which in turn accelerate the axial movements. This process is illustrated in the figure below.

Because of short circuit currents, the magnetic imbalance fault occurs between the low and high windings. The unbalanced magnetic force components in each half of winding are resulted by axial displacement between the magnetic centers of the windings that is leading to alter in its relative position. Due to the progressive nature of winding failure the end-supporting structure which can be caused by faulty unattended. It can simulate this type of fault by neglects the capacitance and change the inductance of particular discs [15]. The 13% of inductance modeled on axial displacement. The 30% and 50% axial displacement affection in the HV winding on the ΔV- Iinlocus as shown in figure 8.

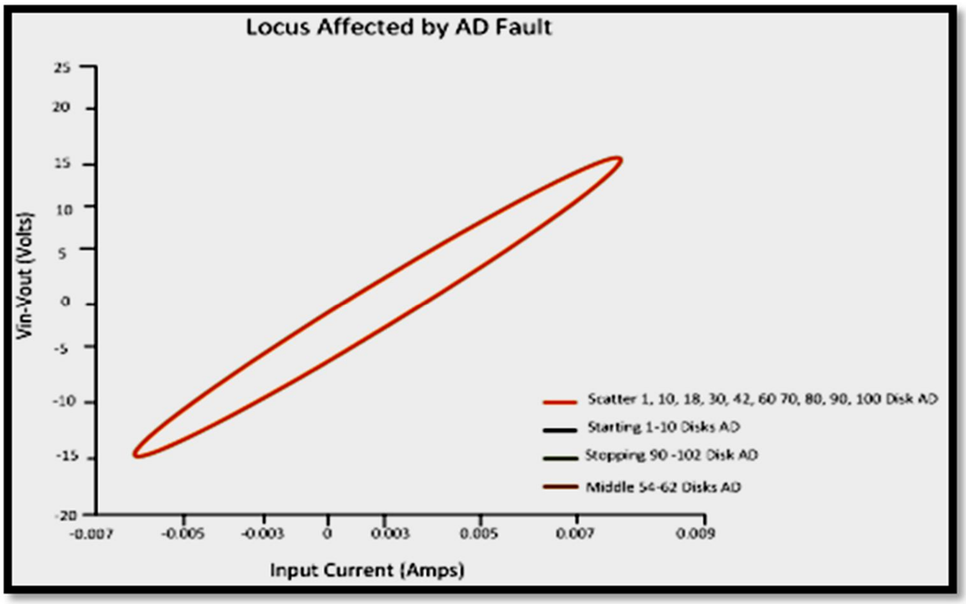

Fig .8: The Effect of Axial Displacement Fault Location on the Locus.

6.3 Buckling Stress

Radial forces occur as a result of the Lorentz force, whereby leakage flux and electrical current creates winding force, thus pulling the inner windings towards the core, and also known as the buckling stress, as well as pushing the outer windings away from the core, as depicted in the figures below.

These forces are generally trivial during standard operating conditions, however when a short circuit occurs the current becomes extremely large in only a short time span. This happens because the electromagnetic force is proportional to the current square, as illustrated in the equation (1) early. This may lead to mechanical forces reaching hundreds of tons in a matter of only milliseconds [18].

Forced buckling occurs when conductors curve in each span or alternate spans in-between axial supporting strips.Free buckling leads to the conductors swelling outwards or inwards at one or more precise location points [10].

Detection is much harder due to the overall change in capacitance and also because the inductance is lower compared to force buckling.The radial force on windings pulls the inner windings close to the core (buckling stress) whereas the outer winding pushes toward the limb (tensile stress) that is caused by current in and leakage flux [16].

It can reduce the inter-winding capacitance and the mutual inductance between the windings at the position of deformation for simulating the Buckling stress in the distributed model. Because of reduces the distance between winding and the core, the shunt capacitance increases [17].

In this work, 10% increasing of shunt capacitance is decreasing the inductance and series capacitance by 10%.that is to modeling of force bucking. As the number of fault level increases, the buckling stress is increasing the locus area and the majority of axis slightly rotates in the clockwise direction contrarily the axial displacement effect.

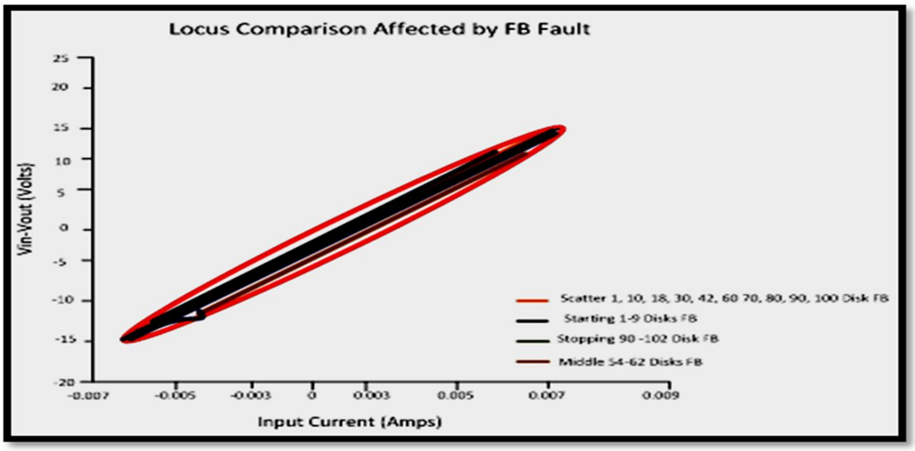

Fig .9: The Effect of Forced Buckling Fault Location on the Locus.

6.4 Leakage Fault

Leakage faults reduce the insulation’s dielectric strength and ultimately decrease the ground resistance. They are usually caused by damage to the insulation or ground shield, abrasion or hotspot.The main causes of leakage fault inside the transformer occur due to abrasion, high moisture content in the winding, hotspot, aging of insulation, insulation damage, and ground shield damage [18]. It can simulate this kind of fault by increasing the shunt admittance and shunt conductive [19]. Figure 10 shown below demonstrates the 80% on proposed locus have an effect on shunt conductance and the shunt admittance. In addition, from the figure the major axis are rotating in clockwise direction similar to the case of inter-disk fault and the locus area is increasing as well. At the same number of faulty disks, the locus area on the inter disk fault is larger than the corresponding one in leakage fault.

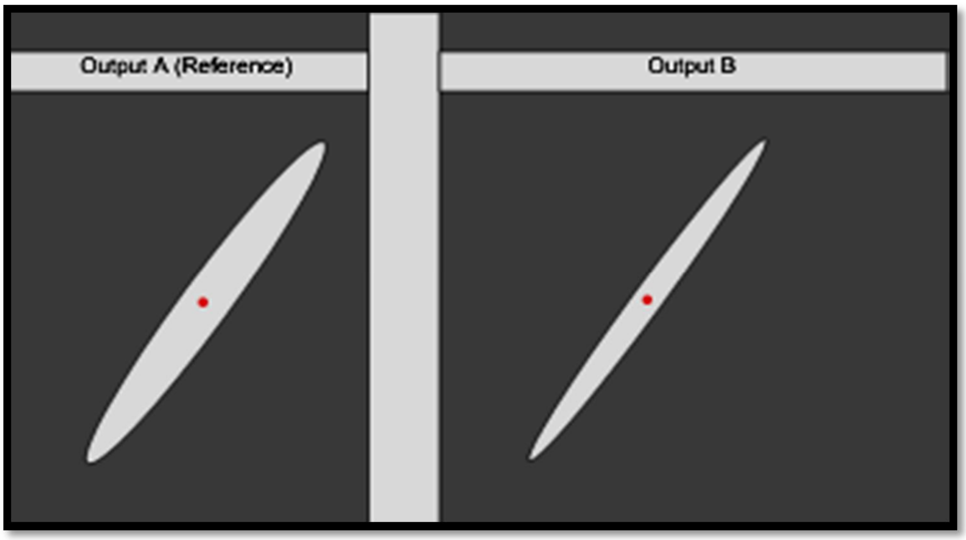

Fig.10: Comparison between a Healthy locus and a 3 Disk Leakage Fault Locus.

Table .1: shows the effect of Faults on Locus Area and Major-Axis Rotation.

Parameter	Axial Displacement(AD)	Disk to Ground	T to T Fault	Disk Deformation and Displacement
Area	-63.4556≤X≤-2.4781	-74.2836≤X≤ 219.1173	7.1446≤X≤ 1784.3326	1.3657≤X≤ 498.7441
Perimeter	0.07944≤X≤ 0.7211	-3.4338≤X≤24.8885	0.6889≤X≤55.8857	0.0014 ≤X≤ 82.3119
Electricity	0.03899≤X≤ 0.4899	-2.8849≤X≤0.4779	-21.3784≤X≤ -0.04859	-0.5833≤X≤-0.0011
Length of centroid	-0.06132≤X≤ 0.1633	-0.1955≤X≤0.0587	-0.0277≤X≤1.9722	-0.5978≤X≤0.1761

The table below, which is based on [10], displays the parameter changes made to the working model for the purpose of inducing a specific kind of fault.

Table .2: Parameter Modification Summary [10].

Type of Fault	Faulty (modification)	Healthy (original)	Percentage Change
Deformation and Displacement	47.64pF Capacitor in series	47.64mF Series Capacitor	Increased by 999999997%
Leakage Faults	$0.22*10^{15}$Ohm Parallel resistor 462pF Shunt Capacitor	$0.22*10^{6}$Ohm Parallel resistor $46.2*10^{3}$pF Shunt Capacitor	0.98 Decreased (98%) 98 Increased (9800%)

Type of Fault	Faulty (modification)	Healthy (original)	Percentage Change
Axial Displacement	13.65mH Series inductor	2.74mH Series Inductor	0.82 Decreased (82%)
Turn to Turn	20Ω Series resistor	Short circuited	0%
Disk to Ground	462pF parallel capacitor	$46.2*10^3$pF shunt capacitor	97 decreased (9700%)
Forced Buckling	462pF Shunt Capacitor 47.64pF Capacitor in series 13.65mH Series inductor	46.2 $*10^3$pF Shunt Capacitor 47.64mF Series Capacitor 2.74mH Series Inductor	85% decreased 9900% increased 999999997% increased

6.5. Discrimination Using Ellipse Features

The ΔV- $I1$ locus is always representing an ellipse as illustrated in mathematical proof and results of the simulation above. It can use unique features of ellipse to compare different loci to identify the type of fault in the power transformer. These features include the major and minor axes lengths, the angle between the major axis and the horizontal axis (θ), ellipse centroid. The measurement and calculation of ellipse eccentricity using MATLAB code [20].

Eccentricity – This is the scalar that specifies ellipse eccentricity which possesses thesecond-moments identical to the region. The eccentricity is determined by calculating the ratio between the ellipse foci and major axis length$\left(\mathbf{1}-\left(\frac{b}{a}\right)\right)^{\mathbf{1/2}}$. The value lies exclusively between 0 and 1. An ellipse with an eccentricity of 0 equates to a circle whilst an eccentricity of 1 equates to a line segment. Perimeter – Scalar; the distance around the region's boundary. MATLAB calculates the perimeter by measuring the distance between each adjoining pair of pixels around the region's border. MATLAB will return unexpected results in the event of images which contain discontinuous regions. The fault is simulated at different number of disks starting from 5 disks to 102 disks as shown in table 3 that demonstrates the angle of rotation of the major axis (θ) with respect healthy locus and the percentage difference in eccentricity (e). As the number of risks of fault increases, both the eccentricity and angle of rotation increases by the inter-disk fault.

There is no effect on the rotation axis and the slightly increasing of eccentricity value as the faulty disks number increase. The eccentricity in force buckling and leakage faults is slightly increased with the increase of faulty disks; however the increment is more noticeable in case of leakage fault. For the large number of faulty disks, when the bulk force of disks of fault increasing than the leakage fault that depends on the significance of the increase in angle of rotation. A minor impact on the eccentricity and a significant impact on the angle of the disk space variationwhen the number of faulty disks increase. There are five cases to validate the developed approach:

Case 1: Matlab software development converts the two loci color in black and white background to perform the major and minor axis lengths, angle, eccentricity and the calculation of ellipse centroid between the horizontal and major axis. Furthermore, the software produces the two loci that there is no difference in angle and eccentricity of two loci rotation as shown in figure (11). This software is a healthy transformer recommended inthis case.

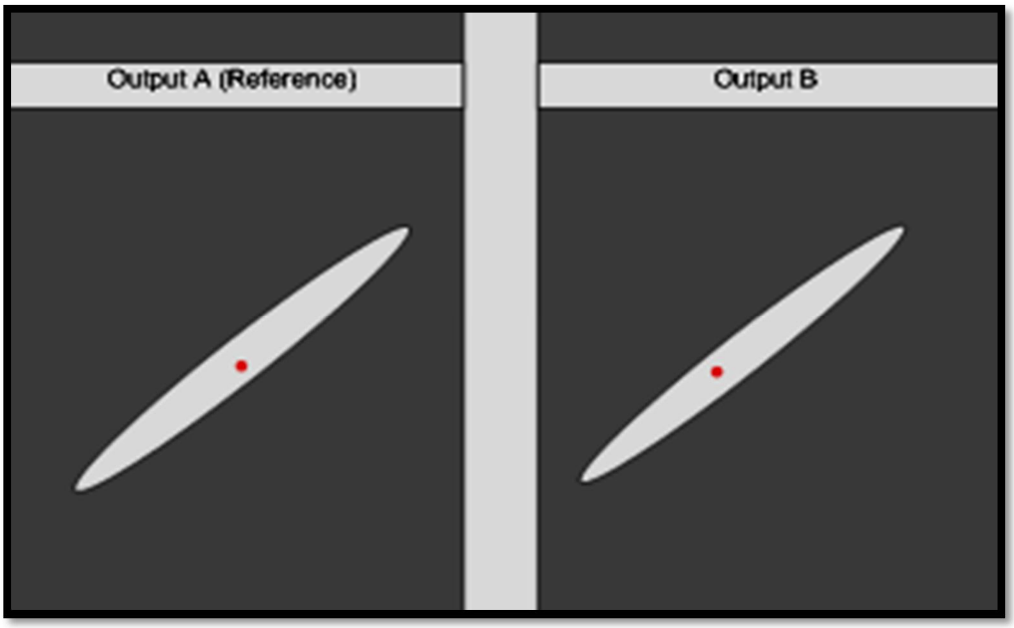

Fig. 11: Comparison of two identical loci

Case 2: Forty four disks are simulated by forcing buckling stress and as shown in figure 12 using developed software for the comparing between the faulty locus and healthy one. The software gives 0.67% and 3.77 differences in eccentricity and the angle respectively.

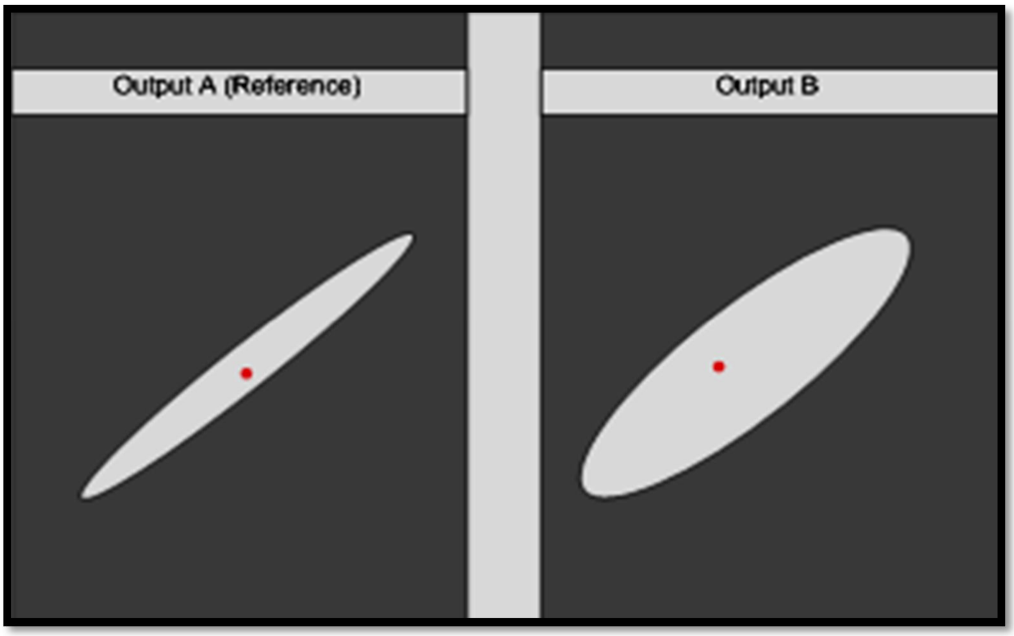

Fig. 12: Comparison of faulty and healthy locus.

Case 3: figure 13 illustrates that the axial displacement fault simulated in 3 disks and 50 disks and the faulty and healthy locus and using developed software for comparing. The software gives in both 0.13 % and 4 % differences in eccentricity and the angle respectively and the axial displacement fault is recommended for this case.The following figure compares a healthy locus with a 50 Disks Axial Displacement Locus.

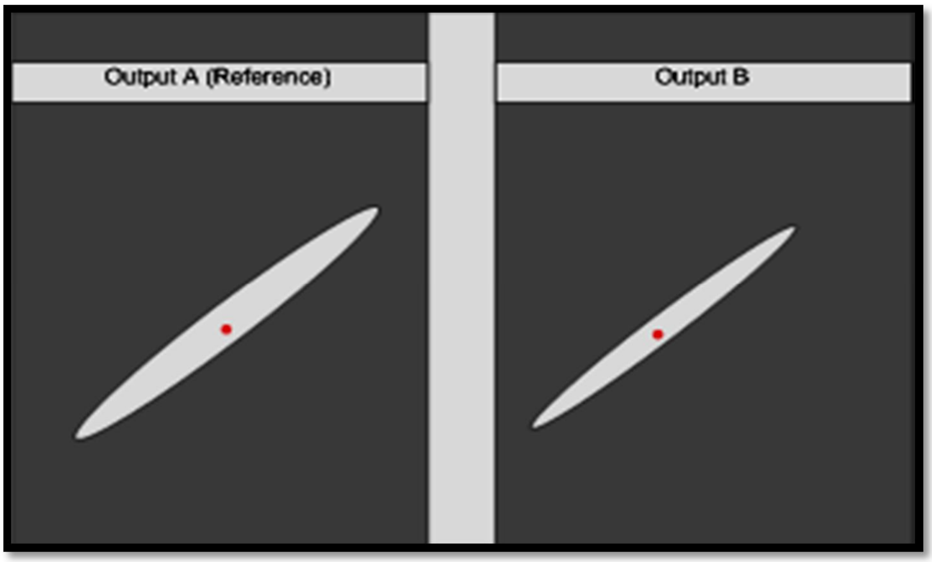

Fig.13: Comparison between a Healthy locus and a 50 Disk Axial Displacement Locus.

The following figure (14) compares a healthy locus with a 3 Disks Axial Displacement Locus,

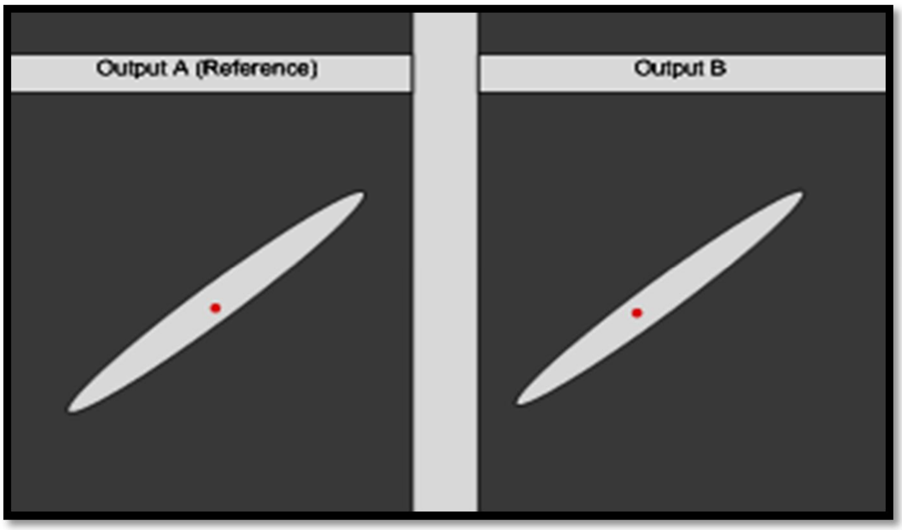

Fig.14: Comparison between a Healthy locus and a 3 Disk Axial Displacement Locus.

Case 4: figures(15) and (16) show the simulation and comparing of leakage fault in 50 disks and 3 disks with a faulty and healthy locus respectively by using the developed software. In this case a forced buckling fault is recommended and it gives 0.60% and 0.53% differences in eccentricity and the angle in respective. The following figure compares a healthy locus with a 50 Disk Leakage Fault Locus.

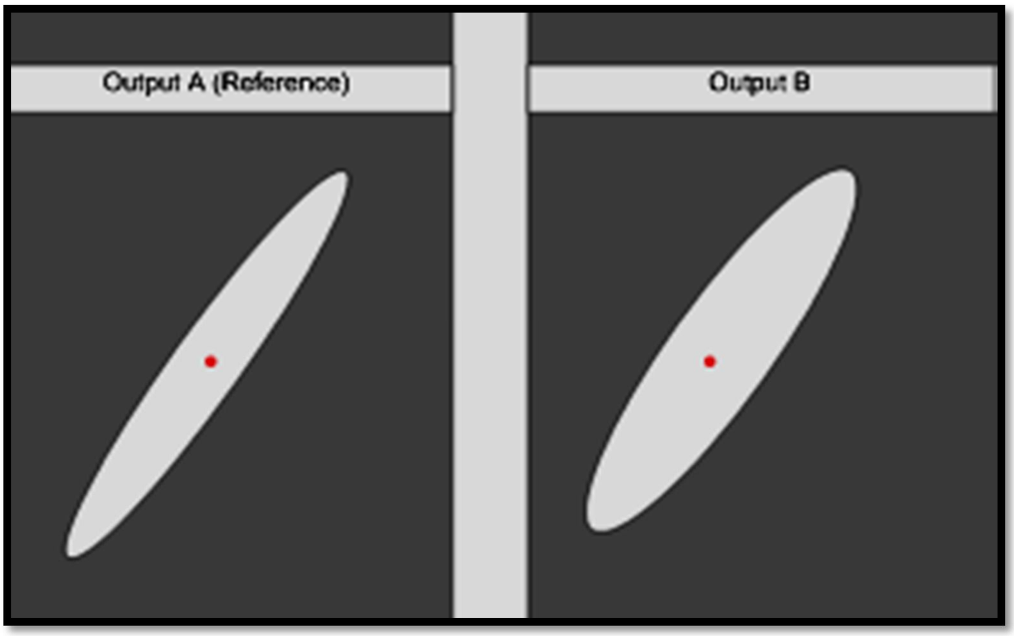

Fig .15: Comparison between a Healthy locus and a 50 Disk Forced Buckling Locus.

The Following figure (16) compares a healthy locus with a 3 Disk Leakage Fault Locus,

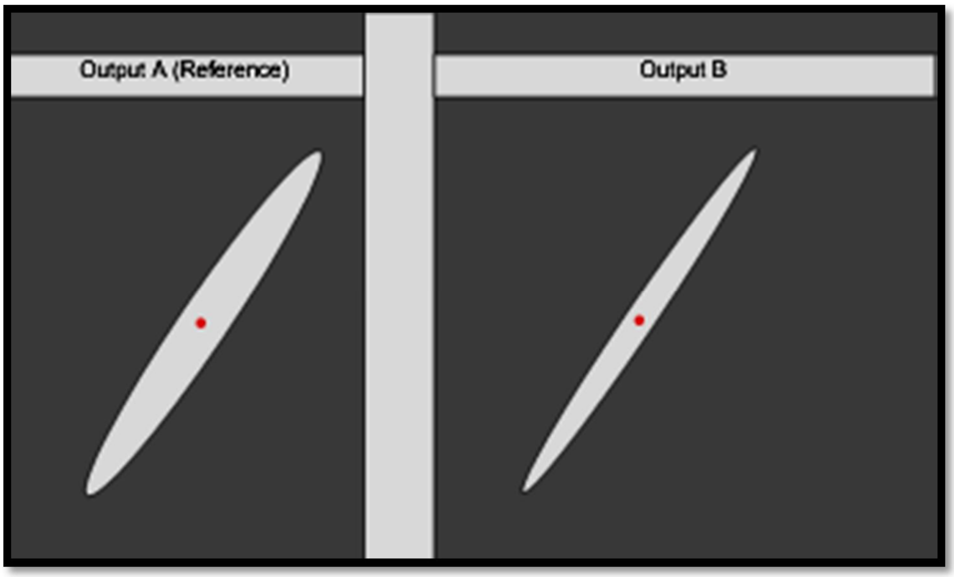

Fig.16: Comparison between a Healthy locus and a 3 Disk Leakage Fault Locus.

Case 5: Testing of laboratory experimental was on single phase transformer of 125/50V, 0.25 KVA as shown in figure (17). A 62.5 Ω resistor and 4% and 10% of the low voltage winding to create turn- turn short circuit for loading the transformer. A digital oscilloscope constructs the ΔV-Iinlocus of the transformer. Figure (18) shown below illustrates the comparison of both the healthy and faulty loci which shows the significant change in the locus area as the number of faulty turn increases, and figure (19) shown below compares a healthy locus with a 3 Disk Turn to turn locus.

The developed software feed the healthy and 9% short circuit turns loci, the percentage difference calculated by the software is 0.18% and 7.34 in eccentricity and the angle of rotation respectively as shown in figure 19 and clearly visible in two loci that are generated by the developed software. As shown in table(3) the significant difference in the range of turn to turn the short circuit well with the angle of rotation aligns. The practical test was carried out in Curtin University's Power System Lab; its purpose was to affirm the simulated testing as shown in figures (18-19). The transformer fault was simulated by using a one phase, multi-tap auto transformer.

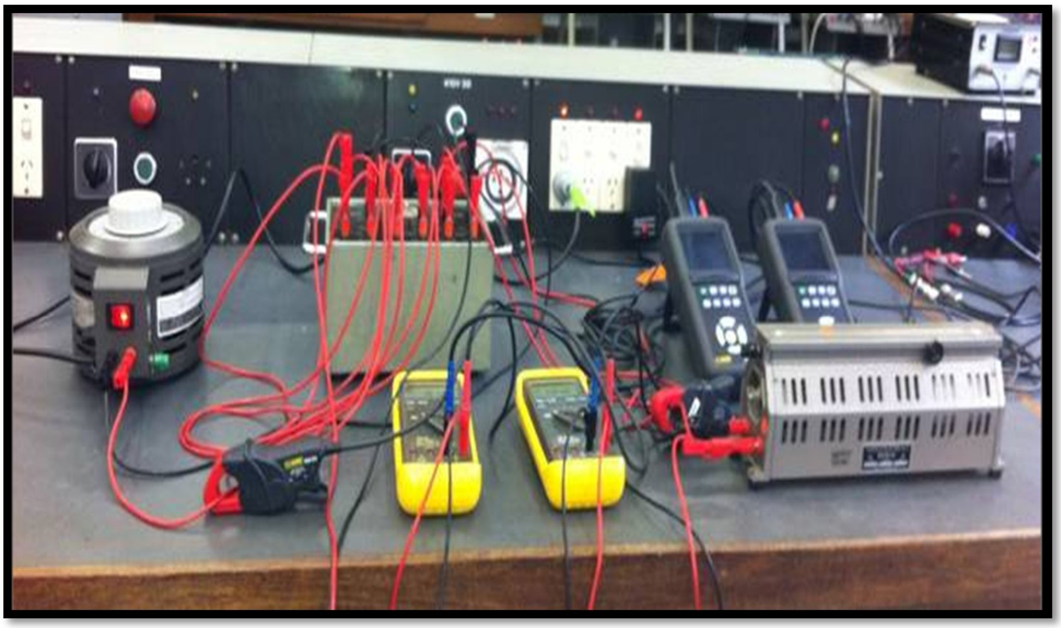

Fig .17: one phase, multi-tap auto transformerLaboratory Equipment at Curtin University Power.

The following figures (18) compare a healthy locus with a 50 Disk Turn to turn Locus,

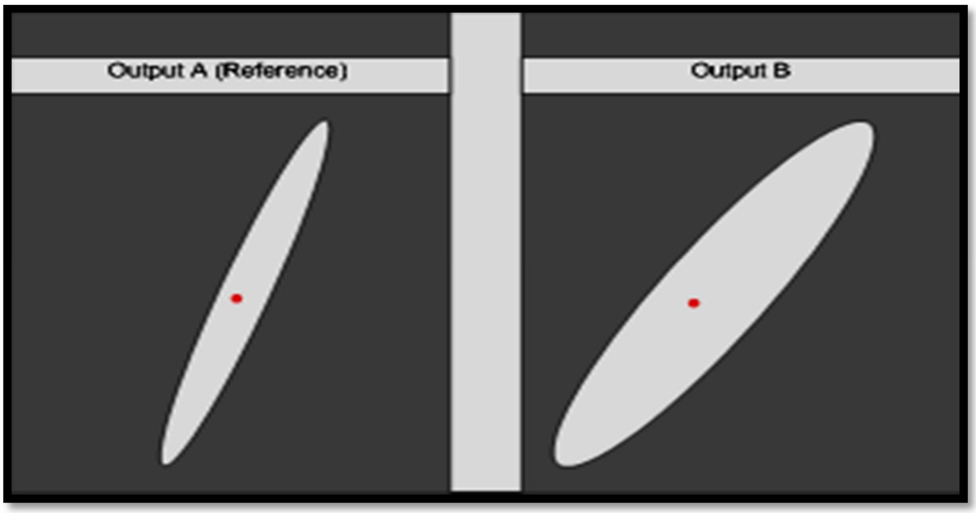

Fig .18: Locus Comparison between a Healthy locus and 50 Disk Turn to Turn Locus.

The following figure (19) is compares a healthy locus with a 3 Disk Turn to turn locus.

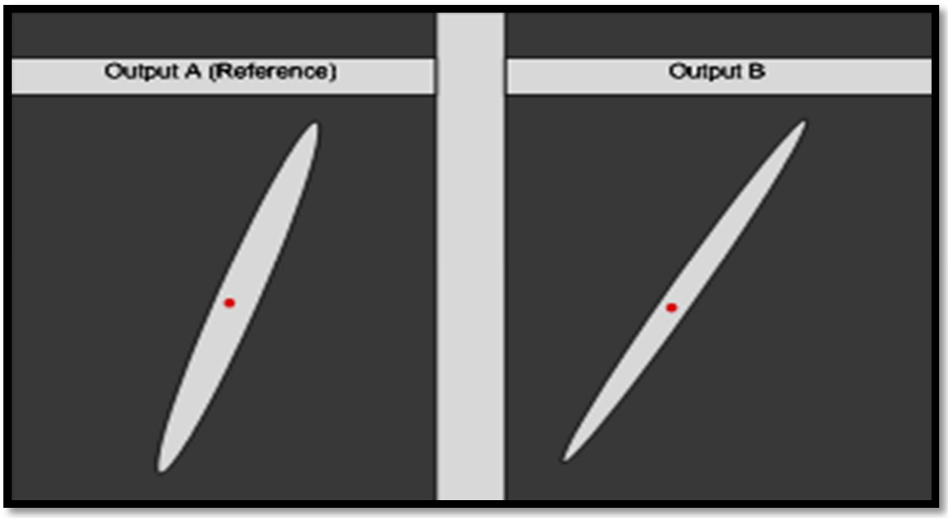

Fig .19: Locus Comparison between a Healthy locus and a 3 Disk Turn to Turn Locus.

Table .3: Illustrates the Summary of Parameter Changes Characteristics.

Differences (%)	Turn to Turn				Axial Displacement				Disk to Ground			
Disk Fault	Perimeter	Angle	Area	Eccentricity	Perimeter	Angle	Area	Eccentricity	Perimeter	Angle	Area	Eccentricity
1 Disk	0.167	-0.12	1.45	-0.0038	0.047	-0.03	-0.59	0.007	-0.681	0.328	-11.5	0.119
3 Disk	0.487	-0.62	4.89	-0.021	0.189	-0.06	-2.02	0.021	-1.789	0.821	-33.7	0.418
4 Disk	0.653	-0.73	7.23	-0.024	0.227	-0.10	-2.43	0.029	-2.468	1.251	-52.1	0.514
5 Disk	0.742	-1.00	7.85	-0.029	0.087	-0.10	-2.87	0.036	-3.119	1.198	-64.8	0.586
10 Disk	1.417	-1.87	17.5	-0.063	0.112	-0.17	-6.85	0.073	-2.884	1.298	-71.7	0.6142
15 Disk	1.779	-2.86	8.89	-0.11	0.118	-0.32	-9.86	0.147	-0.854	0.65	-16.9	0.1889
30Disk	3.887	-6.87	71.5	-0.388	0.238	0.58	-19.8	0.198	2.889	-2.85	40.4	-0.674
45Disk	6.887	-12.5	159	-1.086	0.328	-0.78	-31.8	0.485	6.568	-4.45	89.4	-1.235
55Disk	13.87	-17.3	273	-1.898	0.388	-1.14	-37.4	0.342	16.338	-11.4	153	-2.881
65Disk	19.62	-22.8	389	-3.142	0.598	-1.21	-42.7	0.439	21.589	-14.8	171	-4.111
75Disk	31.31	-31.5	626	-6.489	0.599	-1.13	-47.1	0.389	23.857	-16.2	187	-3.142
90Disk	59.78	-63.5	1189	-17.371	0.543	-1.45	-69.1	0.487	25.894	-20.8	221	-2.998
102Disk	66.73	-89.2	1493	-27.895	0.681	-1.66	-79.7	0.644	29.887	-26.7	267	-3.446

7. CONCLUSION

This project has successfully introduced, explained and justified a new technique for monitoring the mechanical faults which often plague power transformers. This technique supersedes the conventional technique which is presently employed in the electrical utility market. This new technique possesses the ability to handle a large quantity of transformers in a way that is both efficient and cost-effective.

It will undoubtedly increase network reliability due to the online monitoring function present in this technique. Early fault detection means that the normal costs associated with transformer failure will be greatly reduced. The technique was essentially carved out by looking at the different load changes and how this affects the fault characteristics, thus making the fault identification process much clearer and more accurate. The system harmonics are conspicuous because of the unique impact on the locus characteristic.

The monitoring technique employed MATLAB software to assist the user in conducting measurement and analysis. The user does not require high level knowledge and skills in order to analyze and interpret faults because the software will indicate the condition and alert the user as to whether a fault is present or not. Lastly, the practical test results for the turn by turn fault matched the results generated by simulation testing.

8.Knowledment:

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