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Classification of Transformer Core and Winding Conditions from SFRA Measurement Using Statistical Parameter

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ABSTRACT

Power transformers are essential components of power systems and often the most valuable asset in any substation. At site, lightning impulses and cable faults will cause a massive electromagnetic forces to the winding, thus will cause it to deform. A deformed winding will cause damage on the insulation and changes of the turn ratios. This will eventually reduce the reliability of the transformer. . In order to maximize the lifetime and efficacy of a transformer, it is important to be aware of possible faults that may occur and to know how to detect them early. Various frequency sub-bands would indicate the existence of mechanical or electrical problem due to the core and winding of the transformer. In order to determine the faults, numerical parameters such as the Cross Correlation Function and the Standard Deviation are used.

***Keywords**:* Cross Corelation Function, Standard Deviation

1. INTRODUCTION

Power transformers are essential components of power systems and often the most valuable asset in any substation. The reliability of power system depends on trouble-free of transformer used in the power electrical substations.At site, lightning impulses and cable faults will cause a massive electromagnetic force to the winding.These forces are known as radial and axial. Both radial and axial forces related to the current and flux interactions. Winding failure could lead to a major internal arc the tank may rupture with resulting fire and collateral damages.

Sweep Frequency Response Analysis (SFRA) is an effective diagnostic method which is used to detect winding deformation of a transformer. Sweep Frequency Response Analysis (SFRA) is the ratio of a steady sinusoidal output from a test object subject to a steady sinusoidal input. The concept of SFRA is purely a comparative method, which have three method of comparison which are results that will be compared to previous results of the same unit,type-based where the SFRA of one transformer will be compared to an equal type of transformer and lastly phase comparison in which the SFRA results of one phase will be compared to the results of the other phases of the same transformer (Figure 1.1).

The magnitude of the signature obtained from SFRA measurement is in frequency domain. This means each range of frequency has correlation with transformer transfer function[1]. In order classify the type of defects three frequency ranges are defined as in Table 1.1.

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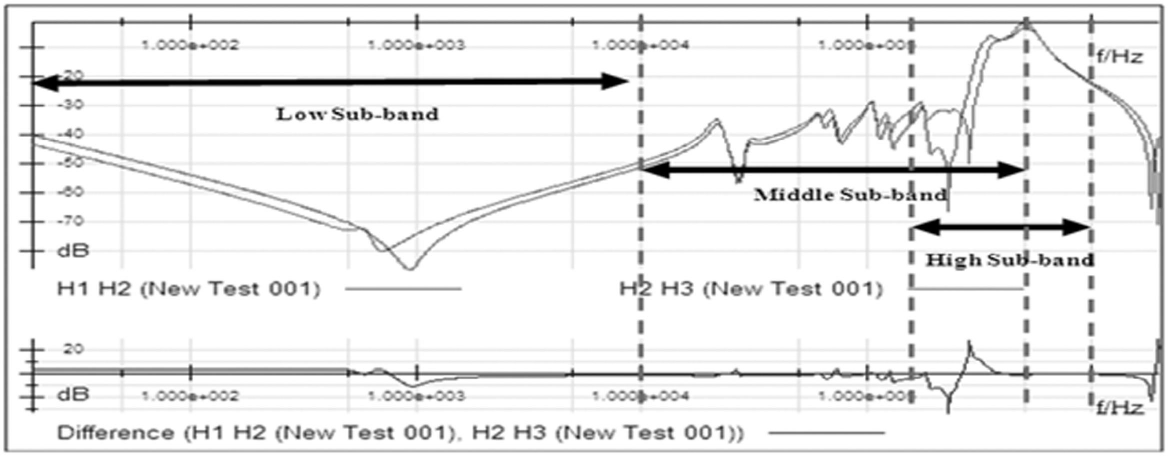


Figure 1: SFRA comparative method (phase to phase comparison)

Table 1
Frequency ranges used in SFRA interpretation [3]

Frequency Sub-bands	*Sensitive to Elements*
Low Frequency 20 Hz to 10 kHz	Transformer core and winding inductance problem
Medium Frequency 10 kHz to 500 kHz	Transformer winding deformation due top radial movements
High Frequency 200 kHz to 1 MHz	Transformer winding deformation due to axial movements

SFRA comparative method is highly dependent on the experience of the interpreter and severity of the deformation could not be determined. In order to enhance SFRA method, statistical approach was used to analysis the SFRA raw data.

SPSS statistic is a software package used for statistical analysis. This statistical software will be used to determine severity of the defect. The statistical parameters used are Cross Correlation Function (CCF) and Standard Deviation (SD) method. Cross-correlation takes two sets of numbers and looks at how similar they are. If two series of numbers such as an SFRA trace perfectly or nearly match, that would have a CCF very close to 1. If two traces have absolutely no correlation, in other words are completely random, then those values would have a CCF of 0. Upon performing the calculation, for CCF if the value is closer to one then there is high correlation which indicates the transformer is in good condition. As for SD, the closer calculated value to 0, it indicates the transformer is in good condition. SPSS software has a standard built in formula that is used to obtain the CCF value and for SD the formula is generated using Transform → Compute Variable.

$$SD_{(x,y)} = \sqrt{\frac{\sum_{i=1}^{N}\left[Y_i - X_i\right]^2}{N}}$$

where:

SD_{xy} = standard deviation betweenand

X_i = value from the first set of data in dB

Y_i = value from the second set of data in dB

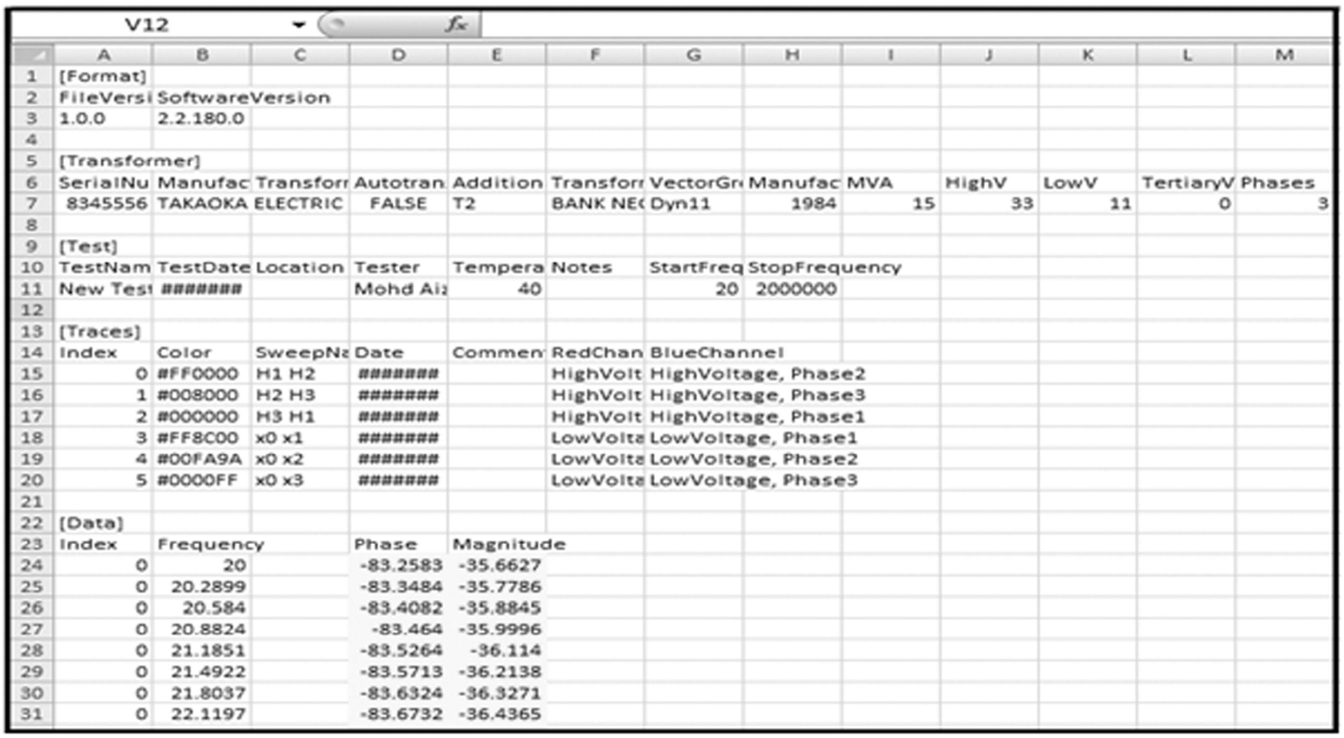
i = the respective frequency point

N = the number of data samples

2. METHODOLOGY

SFRA raw data (Figure 1.1) was obtained for seven transformers from Malaysia's power utility. Six transformers were from non-defect transformer and 1 defect transformer.

Upon obtaining the raw data, the necessary values for the frequency sub-bands stated in Table 2 was filtered out. The filtered data was used to compute CCF and SD values. Upon obtaining the CCF and SD values for all the transformers at every frequency sub-bands, average value for CCF and SD calculated for the six non-defect transformers. The calculated average value was used to calculate the CCF and SD boundary limit. There is no universal formula for statistical testing. Hence for the classification for CCF, the common percentage that is used to calculate limit from a mean value is 5%. [5] As for the SD values where the limits are calculated in the same manner but with a different percentage which is 19.1%. By using these ranges, the boundary limit for CCF (Table 2.1) and SD (Table 2.2) was established. These boundary limits will be able to detect the defected transformers. This boundary limits are important to perform the analysis for the transformer to perform classification, if the average CCF that falls within the upper and lower range, then the core and winding at that specific frequency and voltage is in good condition. If the average values falls



V12 fx

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	[Format]												
2	FileVersi	SoftwareVersion											
3	1.0.0	2.2.180.0											
4													
5	[Transformer]												
6	SerialNu	Manufac	Transforr	Autotran	Addition	Transforr	VectorGr	Manufac	MVA	HighV	LowV	TertiaryV	Phases
7	8345556	TAKAOKA	ELECTRIC	FALSE	T2	BANK NE(	Dyn11	1984	15	33	11	0	3
8													
9	[Test]												
10	TestNam	TestDate	Location	Tester	Tempera	Notes	StartFreq	StopFrequency					
11	New Test	#######		Mohd Ai	40		20	2000000					
12													
13	[Traces]												
14	Index	Color	SweepNa	Date	Commen	RedChan	BlueChannel						
15	0	#FF0000	H1 H2	#######		HighVolt	HighVoltage, Phase2						
16	1	#008000	H2 H3	#######		HighVolt	HighVoltage, Phase3						
17	2	#000000	H3 H1	#######		HighVolt	HighVoltage, Phase1						
18	3	#FF8C00	x0 x1	#######		LowVolta	LowVoltage, Phase1						
19	4	#00FA9A	x0 x2	#######		LowVolta	LowVoltage, Phase2						
20	5	#0000FF	x0 x3	#######		LowVolta	LowVoltage, Phase3						
21													
22	[Data]												
23	Index	Frequency		Phase	Magnitude								
24	0	20		-83.2583	-35.6627								
25	0	20.2899		-83.3484	-35.7786								
26	0	20.584		-83.4082	-35.8845								
27	0	20.8824		-83.464	-35.9996								
28	0	21.1851		-83.5264	-36.114								
29	0	21.4922		-83.5713	-36.2138								
30	0	21.8037		-83.6324	-36.3271								
31	0	22.1197		-83.6732	-36.4365								

Figure 2: Sample Raw Data Obtained from TNB Distribution in Excel

Table 2
Values of 5% Range for CCF

	CCF:5%	*LF (20 Hz to 10 kHz)*	*MF (10 kHz to 500 kHz)*	*HF (200 kHz to 1 MHz)*
HV	Upper Limit	1,0311	1.0175	1.0156
	Mean	0.982	0.969	0.9672
	Lower Limit	0.9329	0.9411	0.9188
LV	Upper Limit	1.03	1.039	1.0235
	Mean	0.9809	0.9895	0.9748
	Lower Limit	0.9319	0.94	0.9261

Table 3
Values of 19.1% Range for SD

	SD:19.1%	*LF (20 Hz to 10 kHz)*	*MF (10 kHz to 500 kHz)*	*HF (200 kHz to 1 MHz)*
	Upper Limit	3.0662	3.4217	2.688
HV	Mean	2.5745	2.873	2.257
	Lower Limit	2.0868	2.3243	1.826
	Upper Limit	2.6375	1.0178	1.481
LV	Mean	2.2145	0.8546	1.2435
	Lower Limit	1.7915	0.6914	1.006

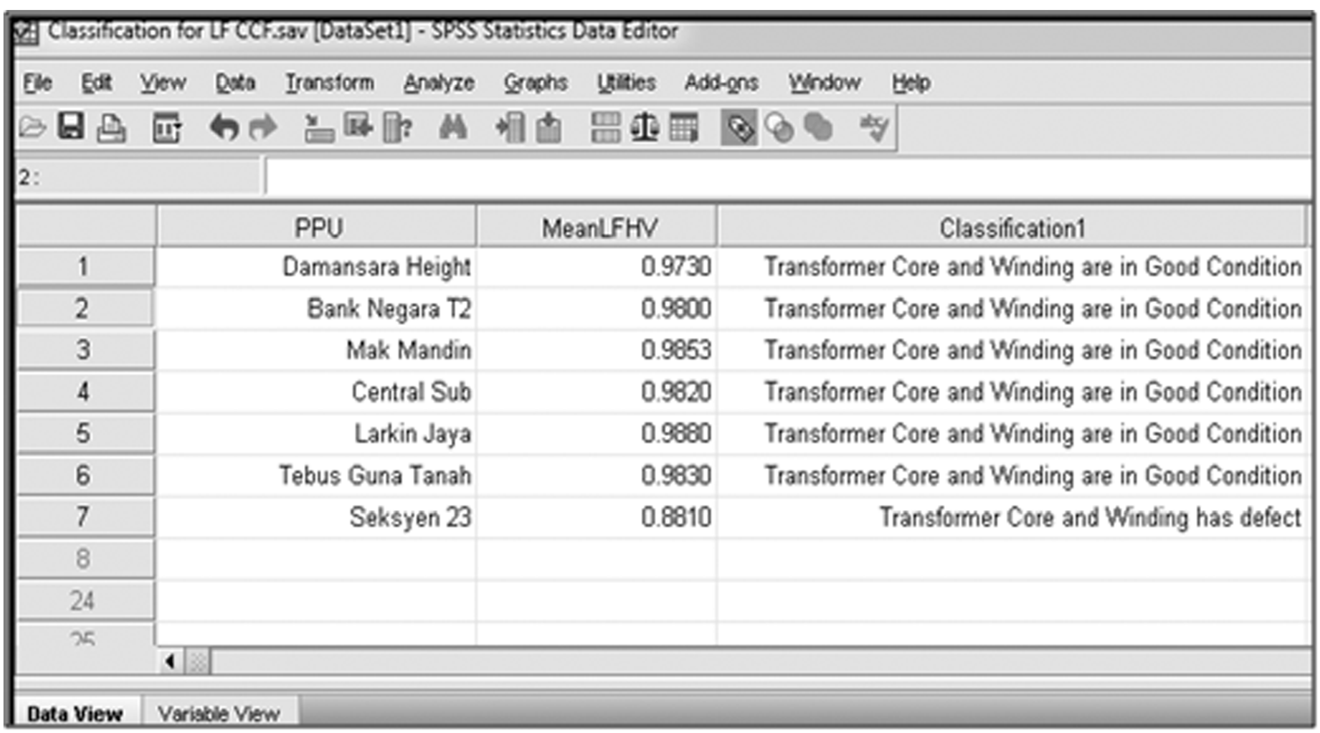
beyond or lower than the limit then, the transformer is said to be defect depending on the range of frequency of occurrence.

3. RESULT & DISCUSSION

By using the CCF boundary limit (Table 2.1), the seven transformers condition was analyzed. The outcome of the analysis could be seen in the Figure 3.1 and Figure 3.2.

Base on Figure 3.1 and Figure 3.2 conducted, it showed that 6 transformers are in good condition and 1 transformer has defect which is from Seksyen 23 substation. The transformer's yellow phase has defect at low voltage and high voltage at low frequency (Figure 3.1) which indicates the transformer has core and winding defect. At high frequency (Figure 3.2), it was found that yellow phase at high voltage has winding axial deformation. SD analysis showed similar finding.

The findings were verified by visual inspection done on the transformer. From Figure 3.3, it can be seen that yellow phase high voltage winding experiencing axial deformation and Figure 3.4 shows there is burn mark in the core.

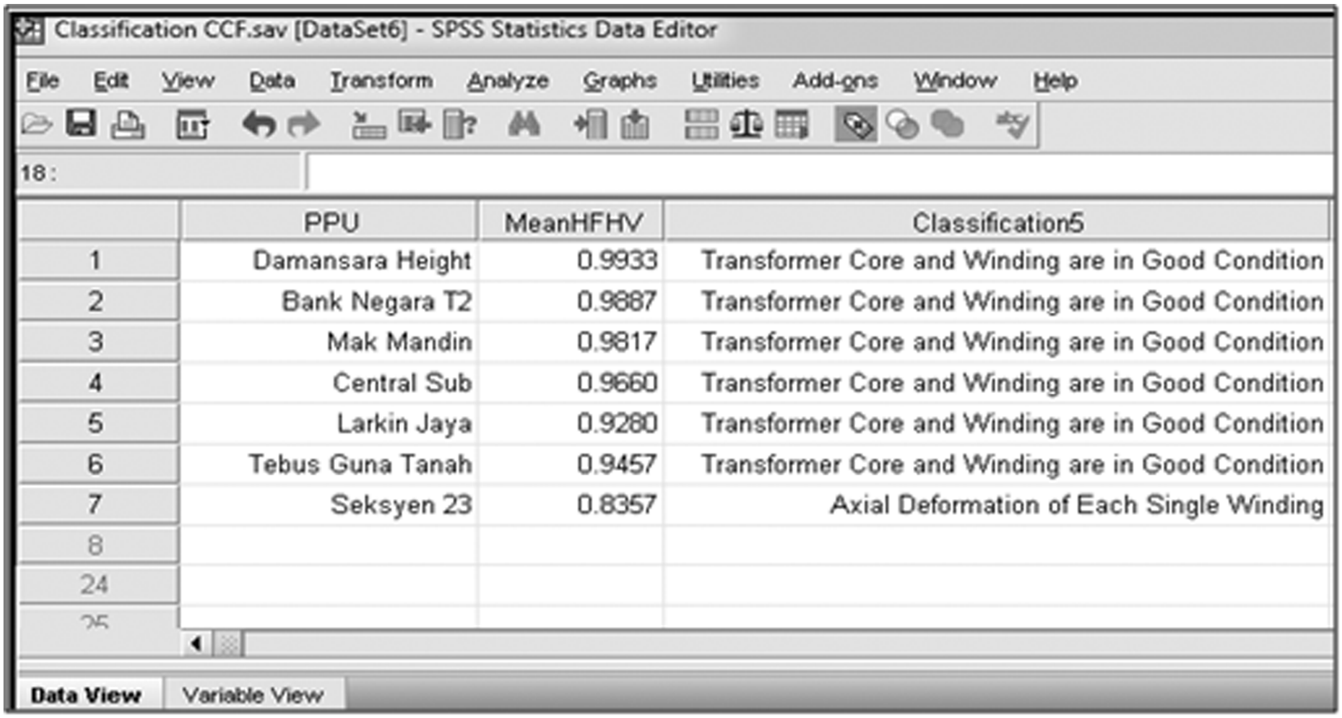

Classification for LF CCF.sav [DataSet1] - SPSS Statistics Data Editor

File Edit View Data Transform Analyze Graphs Utilities Add-ons Window Help

	PPU	MeanLFHV	Classification1
1	Damansara Height	0.9730	Transformer Core and Winding are in Good Condition
2	Bank Negara T2	0.9800	Transformer Core and Winding are in Good Condition
3	Mak Mandin	0.9853	Transformer Core and Winding are in Good Condition
4	Central Sub	0.9820	Transformer Core and Winding are in Good Condition
5	Larkin Jaya	0.9880	Transformer Core and Winding are in Good Condition
6	Tebus Guna Tanah	0.9830	Transformer Core and Winding are in Good Condition
7	Seksyen 23	0.8810	Transformer Core and Winding has defect

Data View Variable View

Figure 3.1: Classification from Low Frequency CCF at Yellow



Classification CCF.sav [DataSet6] - SPSS Statistics Data Editor

	PPU	MeanHFHV	Classification5
1	Damansara Height	0.9933	Transformer Core and Winding are in Good Condition
2	Bank Negara T2	0.9887	Transformer Core and Winding are in Good Condition
3	Mak Mandin	0.9817	Transformer Core and Winding are in Good Condition
4	Central Sub	0.9660	Transformer Core and Winding are in Good Condition
5	Larkin Jaya	0.9280	Transformer Core and Winding are in Good Condition
6	Tebus Guna Tanah	0.9457	Transformer Core and Winding are in Good Condition
7	Seksyen 23	0.8357	Axial Deformation of Each Single Winding

Figure 3.2: Classification from High Frequency CCF at Yellow Phase

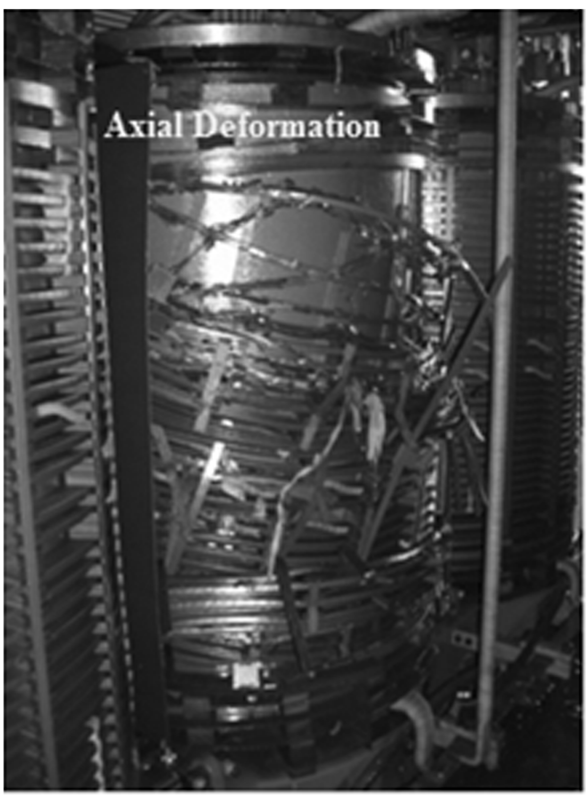


Figure 3.3: HV winding (H2H3 Phase) has moved downwards

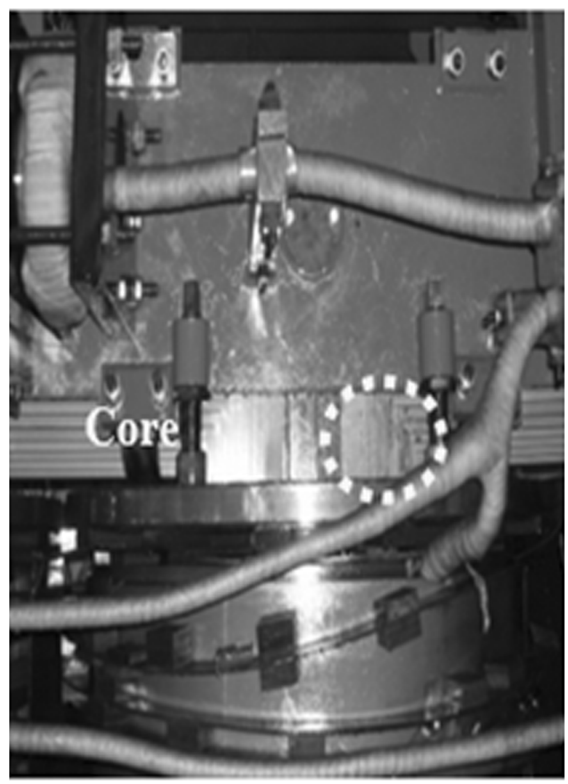


Figure 3.4: Core Defect

4. CONCLUSION

Each of the frequency bands from the SFRA measurement has a significant indication on the condition of the transformer core and winding. In conclusion, the proposed frequency sub-bands, has proven to provide accurate defect of the transformer together with the usage of the SPSS software. SPSS has proven to be suitable software to be used for transformer analysis. The results are reliable as it covers a wide range of frequency to determine the occurred fault, from 20 Hz to 1MHz. The application of SPSS is crucial as it eliminates prediction done based on the results obtained. SPSS and SFRA can be combined for easy analysis of transformer winding condition assessment to be used in the industry.

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