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A case study on saturation of core of R phase unit of three phase bank of 765/400/33KV,1500MVA Transformer at 765KV transmission sub-station

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ABSTRACT:
This paper presents a case study on core saturation of R phase unit of three- phase bank of 1500MVA, 765/400/33KV Transformer due to large current drawn by tertiary winding which was resulted to operate LV WTI protection trip. The three phase bank of 1500MVA ,765/400/33KV transformer-2 was got tripped by picking up trip contact of WTI of R phase unit at 765KV Transmission Sub-station. The design of LV tertiary winding is generally unloaded or rated at 5MVA capacity for connecting the auxiliary LT load.
The core of transformer gets saturated when very high current flows in winding which produced very high flux as proportionate to current . The core is designed at max flux density 1.8 Tesla which can allow the overfluxing of 110% continous of rated value , beyond this value core will get saturated.
Keywords— CT saturation, Open delta, Tertiary winding ,WTI, transformer tripping,

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I. Introduction

Transformer is highly efficient equipment in electrical system having more than 99% efficiency, which are used in transformation of power by stepping up or down as desired voltage level. In power system, Transformer is most necessary and costly equipment in the Generation, Transmission & Distribution network. The power transformation from 765KV voltage level to 400KV voltage level , 765KV transformer is required wherein three nos. single phase unit of 765/400/33KV, 500MVA auto transformer formed the three phase bank of rating 1500MVA, 765/400/33KV. 765kv side bushing of ICT (Inter-connecting transformer) is get connected with 765KV Bus-1 & 2 through dedicated 765KV ICT bay (Circuit Breaker (CB), Isolator, CT) with various transformer and bay protection & relaying i.e. Differential, REF, Back-up impedance and body protection i.e. B'relay, PRD, WTI, OTI ,OSR are installed at transformer tank which operates generally in severe fault occurred inside the transformer.

Winding Temperature Indicator (WTI) is one of the body protection which operates i.e. making trip contact at 110degC due to sudden increment of load or overheating of winding . WTI is designed for measuring the temperature of hot-spot of winding. It mainly consists of temperature sensitive bulb, capillary, built-in current matcher, indicating dial; Temperature sensitive mercury bulb & load current (proportional to load) outputs to current matcher through secondary side of CT. The WTI operating temperature setting is 110degC for Trip , 100degC for Alarm , and other two contacts are used for controlling the fan & pump in cooler bank .

II. Review of Literatures :

Neha et al 2016 analyzed that the Transformer saturation is an area of major concern as the transformers are designed to run near peak magnetizing flux value and if voltage/frequency (V/f) ratio increases, it may

cause the transformer to reach into saturation, which can affect normal operation of the transformer and even cause mal-operation of the protective equipments. [1] José Ramírez-Niño et al 2016 studied the saturation of Magnetic core of transformer in a Power System is the crucial effect which can be attributed solar Geomagnetic Induced Currents (GICs) The saturation may conduce to voltage control problems , generating harmonic currents and heating of transformer and also analyzed that the non-linear behavior of GICs (Geo magnetic Induced Current) due to asymmetric saturation of the magnetic core in the power transformer[2] Davarpanah et al 2010 proposes a new hardware-based method to suppress or prevent the CT saturation. [3] Pandey R. et al 2014 describes the saturation study of current transformer during transient fault [4]

III. Aim of work

The case study of core saturation of R phase unit of three- phase bank of 1500MVA, 765/400/33KV Transformer -2 at 765KV Transmission sub-station.

IV. Sequence of trip incident :

1. 765/400 KV Auto transformer-2 (ICT-2) was hand- tripped on an emergency basis to attend the snapped dropper jumper (765 kV side) of the B-ph unit.
2. The jumper was reconnected and the ICT-2 was charged but tripped within 23 sec on LV-WTI-R-phase.
3. On checking the OTI and WTI meters of all the phases, it was found that the maximum indicator (RED needle) of the R-phase unit LV-WTI was beyond 110°C scale, which confirmed the operation of the WTI of Tertiary winding (LV 33kv winding). Other WTIs of HV (765KV winding) & IV (400KV winding) of same R-phase unit were also checked and found in the normal range.
4. After this, visual inspection of all the equipments in the ICT Main bay, Tie bay and ICT side was carried out and no abnormality was observed in ICT-2. However, in ICT-1 (which is physically in adjacent bay to ICT-2), the tertiary jumper of the R-phase unit (from tertiary bushing IPS to Delta Bus IPS) was found opened and hanging. The ICT-1 was in charged condition. Looking up to the severity of the condition, immediate ICT-1 was hand trippe on emergency basis.
5. Now, since both the ICTs were in OFF condition, to normalize the system, it was decided to charge ICT-1 first (after reconnecting the opened jumper) as it was hand tripped and not fault tripped. Hence, the opened jumper was inspected and reconnected to the tertiary bushing IPS connector. ICT-1 was charged successfully ,however ICT-2 was still in the tripped condition.

V. Diagonistic testing :

Following tests were carried out for confirming healthiness of R-Ph unit of ICT-2-

a. **Magnetizing current of tertiary winding (33KV LV) side –**

Measured at applied volage @235V	**R -ph**	**Y-Ph**	**B-Ph**	**Mag. current of R-ph incremented by morethan 5 times**
Pre-commissioning	17.89mA	17.47mA	18.42mA	
Value after tripping	92.4mA	18.42mA	20.94mA	

b. Winding Resistance @75° C (R-phase, only LV side) –

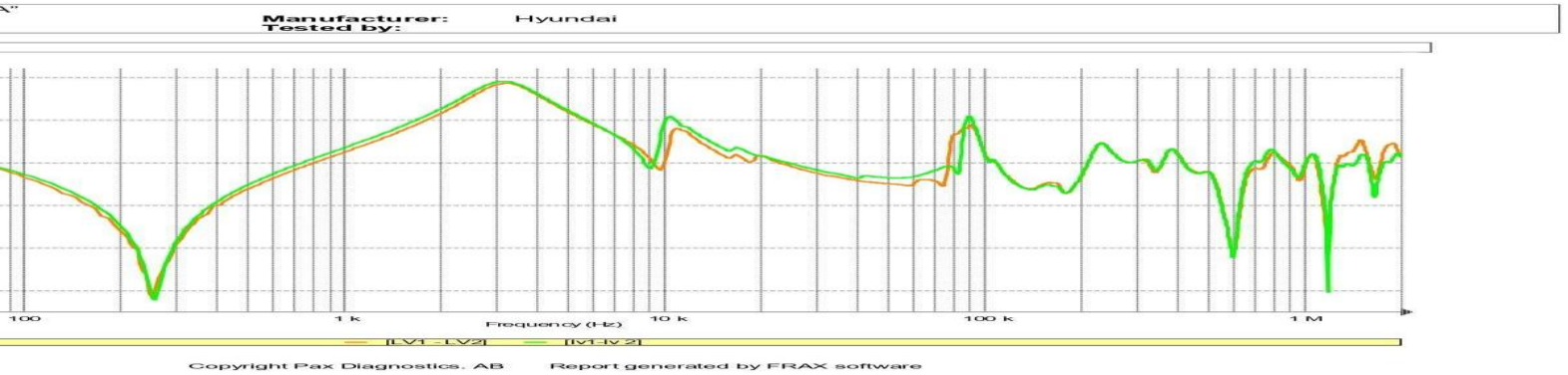
Measured during after tripping	11.94 milli ohms	LV Winding Resistance Valuesare comparable.
Pre-commissioning	11.80 milli ohms	

c. Tanδ and Capacitance of Bushing of Rph unit

Bushing-	Measurement during	**Tanδ (in %)**		**Cap (in nF)**	
		2KV	10KV	2KV	10KV
LV-3.1	Pre-commissioning	0.482	0.482	278.18	278.19
	After tripping	0.408	0.408	278.96	278.95
LV-3.2	Pre-commissioning	0.434	0.435	280.90	280.91
	After tripping	0.493	0.494	282.09	282.10
IV-2.1	Pre-commissioning	0.419	0.421	545.25	545.23
	After tripping	0.392	0.394	547.11	547.26
HV-1.1	Pre-commissioning	0.336	0.338	597.14	597.16
	After tripping	0.3102	0.3112	596.92	596.95

d. Tanδ and Capacitance of Transformer winding (R phase unit)

HV+IV+N/LV OTI Temp 38°C	**Tanδ (in %)**	**Cap (in nF)**



GST	Precommissioning	0.209	0.206	12.913	12.913
	After tripping	0.234	0.218	12.860	12.860

e. Insulation Resitance between Windings :

Measurement Connection	**At 5kV**			**DAI (60/15)**	**PI (600/60)**
	15 s	**60 s**	**600 s**		
(HV+IV+N) to Earth	20.1	75.3	96.1	3.74	1.27
LV to Earth	14.68	138.0	380.0	9.4	2.75
(HV+IV+N) to LV	28.1	245	328.0	8.72	1.34
(HV+IV+N+LV) to Earth	8.89	19.4	34.8	2.18	1.79

f. Core-Insulation test :

Connection	**Voltage**	**Duration**	**IR Value (in GΩ)**
CC-CL	1 kV	60 sec	16.17
CL to Earth	1 kV	60 sec	11.3
CC to Earth	1 kV	60 sec	15.0

Sweep Frequency Response Analysis (SFRA) – Comparision between graph in green colour showing taken during precommisioning & graph in Red colour showing taken aftrer tripping as shown below-

DGA (Dissolved Gas Analysis) testing for transformer Oil

TEST REPORT

SAMPLE DETAILS

Sampling Date:	12/Apr/21	Oil Temp. °C	34
Receipt Date:	13/Apr/21	Wdg Temp. °C	34
Testing Date:	21/Apr/21	Load	
Next Due Date:	**13/Jul/21**	voltage, in kV	

Sample Description: *Insulating Oil Sample in 50 ml Glass Syringe*
Condition on Receipt: OK
Sample Remarks: **200104561**

EQUIPMENT DETAILS

Station:	BINA	Cooling:	OF
Equipment:	765 KV AT 2 R	Breather	AIR
Capacity	333 MVA	Oil Type	Napl
Volt.Class	765 KV	Inst.Date:	01/F
Make	HYUNDAI	Last Filt. Date:	
Serial No:	20111141TIG002-004		

TEST RESULTS

Oil Parameters Reference Standard: IS-1866-2017

PARAMETER	Unit Of Measurement	Measured Value	Violation Limit	Test Method
BreakDownVoltage	kV	NT	50 Min.	IEC-60156
Water Content	mg/kg	2	20 Max.	IEC-60814
Resistivity @ 90°C	E12 ohm-cm	NT	0.1 Min.	IEC-60247
Resistivity @ 27°C	E12 ohm-cm	NT		IEC-60247
Tan Delta @ 90°C	--	NT	0.2 Max.	IEC-60247
InterFacialTension@27°C	mN/m	NT	15 Min.	ASTM D- 971
Acidity	mgKOH/g	NT	0.3 Max.	IEC-62021-1
Flash Point	°C	NT	125 Min.	ASTM D-6450
* Sludge & Sediments	%	NT	0.02 Max.	IS-1866
* Appearance				

Test Conditions for Resistivity and Tan Delta Tests: (a) Type of cell used: NT (b) Average Voltage gradient in the sample: NT (c) Test Frequency for Tan-delta test: NT (d) Room Temp(degC): NT (e) RH (%): NT

BDV not tested

* Inhibitor Content Determination (Test Method:ASTM D-2668)

DBPC	%	NT	---

Dissolved Gas Analysis Test Method: IEC 60567-20
Reference Standard: IEEE-C57.104-2019

PARAMETER	UoM	Measured Value	Viola Limits
Total Gas Content	%	2.63	
Nitrogen (N2)	%	2.13	
Oxygen (O2)	%	0.39	
Hydrogen (H2)	µl/l	3	
Methane (CH4)	µl/l	5	
Ethylene (C2H4)	µl/l	0	
Ethane (C2H6)	µl/l	1	
Acetylene (C2H2)	µl/l	0	
Carbon Monoxide (CO)	µl/l	430	
Carbon Dioxide (CO2)	µl/l	688	

* Furan Analysis (Test Method: IEC-61198: 1993)

2-Furfural	mg/kg	NT	---
5-Hyd Methyl 2-Fur	mg/kg	NT	---
2-Furfuryl Achohol	mg/kg	NT	---
5-Methyl 2-Furfural	mg/kg	NT	---
2-Acetyl-Furfural	mg/kg	NT	---

Inferences from detailed testing :

After analyzing all the test results, it has been concluded that, only the Magnetizing current result of Tertiary Winding has been increased.There is no change in any other test result for any other winding/bushing.it was suggested to carry out the De-magnetizing process of the Tertiary Winding of the R-ph unit. The De-magnetizing was done by applying AC Voltages 415v & 1000V continuously and 2000V intermittent at Tertiary winding terminals and corresponding Magnetizing Current was measured for tertiary winding.

The de-magnetizing results are as follows –

Sr. No.	Day	Voltage Applied	Current Measured	Remarks
1	**Day-1**	**417V**	**128.2mA**	**Continues application :** The de-magnetization was done by applying AC voltage continuous **pre-commissioning value 68.77mA@903V**
2	**Day-2**	**423V**	**176.4mA**	
3	**Day-3**	**1000V**	**143.1mA**	
		903V	**133.1mA**	
4	**Day-4**	2000V	**98.2 mA**	**Intermittent Application :** The de-magnetization was done by intermittent cycle method. 2 kV AC Voltage was applied for 5 minutes after that kept supply off for 5 min. This supply on/off application was repeated for 09 hours. **pre-commissioning value at240 Volts was 20**
5	**Day-5**	2000V	**87.3 mA**	
		2000V	**86.9 mA**	
6	**Day-6**	2000V	**86.5 mA**	

		240V	**36.3 mA**	**mAmp.**

VI. Conclusion:

In this paper, the case study on tripping of three phase bank of 1500MVA, 765/400KV ICT-II due to tripping command issued by LV-WTI (R-ph). The cause of WTI operation due to sudden increase in current in tertiary LV-winding as shown tempreture pointer at 120dgC in LV-WTI (R-phase). The red pointer of WTI indicates the max tempereture of WTI . Further, it was observed that the tertiary jumper of R-ph of ICT-I was found snapped during tripping of ICT-2 due to LV WTI operation.

It is concluded that there may be possibility of circulating current phenomenon which to be required complete study. Further, it may be inferred that de- magnetization process reduces the magnetization current to an extent, but the area of magnetic circuit (core area) of the transformer is very large which is required high voltage for fast de-magnetization. Further, complete de-magnetization of the R - p h unit may not be achieved due to limitation of voltage application source. However, the Magnetizing current of the Tertiary winding was stable at 36.3 milliAmps (@ 240 V AC), whereas the pre-commissioning value was 17.89 milliAmps (@ 240 volts).

Based on diagonistic test results & DGA test results , it is ensured that the R-phase unit of 765/400KV Transformer-2 is healthy. The transformer is successfully charged along with other units.

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