ESKOM

POWER DELIVERY ENGINEERING (PDE)

Control Automation

High Voltage Plant

EIT Training Review: Progress Report

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Contents

1. INTRODUCTION

This paper aims at outlining the progress I achieved in 10 month period as an EiT within PDE at Eskom and also highlights challenges encountered.

The rest of the paper is structured as follows. Two sections outline the work and tasks completed at the HV plant and Control % Automation respectively. A summary section is followed by the conclusion.

2. BACKGROUND

Table 1 below showcases the departments I have rotated since the beginning of the training program. It can be observed from the table that there was a pause in training between July and August. During that period I did self-study on networking and cyber-security using material provided earlier from Control Automation before the beginning of national lockdown due to COVID-19.

Table 1: Departments visited and time spent

DEPARTMENT	PERIOD	DURATION
High Voltage Plant	Mar 2020 -Jun 2020	12 weeks
PTM&C − Control & Automation	Sep 2020 - Present	12 weeks

3. DEFINITIONS & ACRONYMS

3.1 Acronyms

BOC Business Operation Center
DGA Dissolved Gas Analysis
DTM Duval Triangle Method
ECSA Engineering Council of South Africa
EiT Engineer in Training
HMI Human Machine Interaction
NCC National Control Center
OHS Occupational Health and Safety
ONAF Oil Natural Air Forced
ONAN Oil Natural Air Natural
PPE Personal Protective Equipment
PRV Pressure Relief Valve
PTMC Protection Telecomms Measurement and Control
RRM Rogers Ratio Method
SCADA Supervisory Control And Data Acquisition
URS User Requirements Specification

4. HIGH VOLTAGE PLANT

4.1 Transform Basics

This was a fundamental task issued to research the Power transformer role, understand the role of all its major components. This includes further research on the importance of Power transformer oil. The following are the key finding I obtained about the transformer oil:

- **Cooling** - The density of the oil decreases with increasing temperature, as a result, the hot oil at the core and winding will move upward and flow to the radiator and dissipates heat through the surrounding air by conduction process. The cooled oil will then move downwards due to increased density and cool the winding and core. This natural convention process is known as ONAN (Oil Natural Air Natural). For transformers of higher ratings the ONAF (Oil Natural Air Force) method is used, cooling fans are used to fasten the oil heat dissipation to the air through the radiators.
- **Transformer health** - Most of the faults that occur inside the transformer whether electrical and thermal (involving oil or paper insulation) leave behind a trace of gases that become trapped within the oil. Those dissolved gases can be studied. Different gases are formed at different temperatures thus their analysis can provide insight into the temperature the transformer experienced, the type of fault that occurred, and the insulation involved (oil or paper).
- **Transformer compound size** - Transformer oil has high dielectric properties that allow it to withstand high electrical field stress without undergoing electrical breakdown compared to other substances such as natural air. Equation 1 below shows the relationship between electric field strength (E), voltage (V) and distance between live component and grounded component (d). If natural air was used for insulation instead of oil, the equation shows that the distance between the live wire connecting to the winding and the tank will be high to an extent it cannot be transported due to the large area and volume.

$$E = \frac{V}{d} \tag{1}$$

4.2 Gassing Transformer Diagnosis using DGA

With the basic knowledge of the transformer oil involvement to the health of the power transformer, on this assignment, I was tasked to research further on transformer diagnosis using dissolved gas analysis (DGA). I was later provided with data of transformer samples results taken every six months each year for five years as shown in Figure 1. With the data, I had to first use different DGA techniques to detect if the transformer has a fault and then proceed to diagnose it.

Sample date	H_2	O_2	N_2	CH_4	CO	CO_2	C_2H_6	C_2H_4	C_2H_2	Moisture reading
2013/11/07	84	9003	55661	26	86	136	51	11	0	1
2014/05/06	93	3014	43697	42	107	86	82	17	0	7
2014/11/04	75	2247	41555	49	119	389	96	20	0	3
2015/05/05	65	2801	49238	81	120	528	127	44	0	5
2015/11/04	49	2687	49813	100	123	618	146	62	0	5
2016/05/05	41	2560	54990	128	132	528	193	80	0	4
2016/11/02	42	2251	52823	135	128	625	188	90	0	7
2017/05/04	28	4576	57925	140	118	522	228	94	0	11
2017/11/01	35	3197	59794	177	175	754	243	104	0	8
2018/05/03	35	2593	58770	201	162	301	286	136	0	4

Figure 1: Five years samples record for transformer

4.2.1 ***Detecting*** **Key-gas** Key-gas is the 1st method I used to detect the state of the transformer. The method uses the concentration of individual gas level for detecting, each outstanding gas relates to a certain fault. Table 2 below shows the summary of the key-gas method.

Table 2: Key-gas method (IEEE std.C57.104-2008)

KEY GAS	FAULT TYPE	TYPICAL PROPORTIONS OF GENERATED COMBUSTIBLE GASES
C_2H_4	Thermal oil	Mainly C_2H_4. Smaller proportions of C_2H_6, CH_4 & H_2. Traces of C_2H_2 at very high temperature level
CO	Thermal oil and cellulose	Mainly CO, much smaller quantities of hydrocarbon, gases in same proportions as thermal faults in oil alone
H_2	Electrical Low Energy Partial Discharge	Mainly H_2, smaller quantities of CH_4, traces of C_2H_4 and C_2H_6
H_2 and C_2H_2	Electrical High Energy (arcing)	Mainly H_2 and C_2H_2, minor traces of CH_4, C_2H_4 and C_2H_6, also CO if cellulose is involved

From Figure1 the outstanding gas is Carbon-monoxide, which implies the transformer is experiencing thermal oil and cellulose fault, but that condition also requires the other key-gases to be in smaller proportion [1] of which the provided data does not fully satisfy. In this case, I could not make a decision based on that result only.

Individual & Total Dissolved Key-Gas Concentration The solution to the problem was the application of Individual & Total Dissolved Key-Gas Concentration method [2]. This is a four-condition DGA guide (each condition has a range of concentrations) that uses the sum of combustible gases concentration. The results of this tool showed the transformer to be partially operating satisfactorily except for the last two samples tested, which showed that the fault may be present. These results are shown by Figure 2 below.

Sample date	Status
2013/11/07	Condition 1: Operating satisfactorily
2014/05/06	Condition 1: Operating satisfactorily ($C2H6$ should be investigated, exceed limits)
2014/11/04	Condition 1: Operating satisfactorily ($C2H6$ should be investigated, exceed limits)
2015/05/05	Condition 1: Operating satisfactorily ($C2H6$ should be investigated, exceed limits)
2015/11/04	Condition 1: Operating satisfactorily ($C2H6$ & $C2H4$ should be investigated, exceed limits)
2016/05/05	Condition 1: Operating satisfactorily ($C2H6$ & $C2H4$ should be investigated, exceed limits)
2016/11/02	Condition 1: Operating satisfactorily ($C2H6$ & $C2H4$ should be investigated, exceed limits)
2017/05/04	Condition 1: Operating satisfactorily ($C2H6$ & $C2H4$ should be investigated, exceed limits)
2017/11/01	Condition 2: A fault may be present ($C2H6$ & $C2H4$ should be investigated, exceed limits)
2018/05/03	Condition 2: A fault may be present ($C2H6$ & $C2H4$ should be investigated, exceed limits)

Figure 2: Individual & Total Dissolved Key-Gas Concentration method results

4.2.2 ***Diagnosing*** In interpreting gas analysis results, relative gas concentrations are found to be more accurate compared to the actual concentrations, thus for diagnosing the transformer the two widely used and recommended ratio methods were adapted. These methods should only be applied if the problem exists (not for detecting) as it was established in sub-section 3.2.1.

Rogers Ratio Method (RRM)

This method uses five different gas concentrations to calculate three useful ratios that together define a given condition. When this method was developed, measurements were taken mostly from conservator type transformer (Type III transformer), making this method suitable for diagnosing the transformer in question. Figure 12 in the Appendix shows the summary of this method including types of faults relative to the concentrations.

Figure 3 below showcases the calculated gases ratios used to diagnose the transformer. Using these calculated ratios with the help of Figure 12 on the Appendix, the transformer was found to be experiencing the thermal fault. This method further highlighted that this issue involves cellulose insulation (production of CO and CO_2), which is supported by the key-gas method results aforementioned that showed carbon monoxide to be formed in greater quantities. These results are shown in Figure 4 below.

With the fault and the temperatures involved found, my research showed that the transformer can continue normal operation but the oil sampling interval should change from 6 months to quarterly on monthly depending on the gases generation rate, if the condition worsens then the transformer operation should be shut down. Like the key-gas method discussed above, this method does not guarantee answers hence the 2^{nd} method was necessary to verify RRM diagnosis results.

Sample date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2		$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$
2013/11/07	84	26	51	11	0		-	-	-
2014/05/06	93	42	82	17	0		0	0.452	0.207
2014/11/04	75	49	96	20	0		0	0.653	0.208
2015/05/05	65	81	127	44	0		0	1.246	0.346
2015/11/04	49	100	146	62	0		0	2.041	0.425
2016/05/05	41	128	193	80	0		0	3.122	0.415
2016/11/02	42	135	188	90	0		0	3.214	0.479
2017/05/04	28	140	228	94	0		0	5	0.412
2017/11/01	35	177	243	104	0		0	5.057	0.428
2018/05/03	35	201	286	136	0		0	5.743	0.476

Figure 3: Calculated gas ratios

Sample date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2		Fault Type	Problem found
2013/11/07	84	26	51	11	0		-	-
2014/05/06	93	42	82	17	0		No fault	-
2014/11/04	75	49	96	20	0		No fault	-
2015/05/05	65	81	127	44	0		Thermal F 150-300°C	-This issue could be stray flux in the tank. -overheating of copper conductor from eddy current -This issue involves cellulose insulation, which will produce CO and CO_2
2015/11/04	49	100	146	62	0		Thermal F 150-300°C	
2016/05/05	41	128	193	80	0		Thermal F 150-300°C	
2016/11/02	42	135	188	90	0		Thermal F 150-300°C	
2017/05/04	28	140	228	94	0		Thermal F 150-300°C	
2017/11/01	35	177	243	104	0		Thermal F 150-300°C	
2018/05/03	35	201	286	136	0		Thermal F 150-300°C	

Figure 4: RRM Diagnosing results

Duval Triangle

This method uses the percentage contribution of three gases, both the equation to calculate these percentages and requirements needed to apply this method are shown by Figure 13 and 14 on Appendix. The research I conducted showed that all cases are resolved using this method and give 96% of correct diagnosis.

Figure 5 below showcases the calculated percentage contribution of each gas per sample. Change in concentration is the difference between the concentration of the sample in question and the previous sample concentration.

Sample date	CH_4	C_2H_6	C_2H_4	C_2H_2	ΔCH_4	ΔC_2H_4	ΔC_2H_2	$\%CH_4$	$\%C_2H_4$	$\%C_2H_2$
2013/11/07	26	51	11	0	-	-	-	-	-	-
2014/05/06	42	82	17	0	-	-	-	-	-	-
2014/11/04	49	96	20	0	7	3	0	70	30	0
2015/05/05	81	127	44	0	32	24	0	57.14	42.86	0
2015/11/04	100	146	62	0	19	18	0	51.35	48.65	0
2016/05/05	128	193	80	0	28	18	0	60.87	39.13	0
2016/11/02	135	188	90	0	7	10	0	41.18	58.82	0
2017/05/04	140	228	94	0	5	4	0	55.56	44.44	0
2017/11/01	177	243	104	0	37	10	0	78.72	21.28	0
2018/05/03	201	286	136	0	24	32	0	42.86	57.14	0

Figure 5: Duval Triangle gases percentage contribution

Figure 6 showcases the plot of gases percentages for selected samples. Lines are drawn across the triangle for each gas parallel to hash marks visible on each side of the triangle. The triangle has 7 diagnostic regions the state of the transformer may be at, this region is the point where all the three lines intersect. Figure 7 below showcases the diagnosis results for all samples. All sample results showed the transformer to be experiencing the thermal fault, thus validating the Rogers ratio method results.

The results however also show that the transformer experienced the thermal fault with a temperature greater than 700^{o}C. At such a temperature, acetylene would have been formed. It can be observed on the provided data in Figure 1 that the concentration of acetylene is 0 for all the samples, this shows the transformer never exceeded more than 500^{o}C, which is the minimum temperature that can result in the traces of acetylene in the transformer oil. The conclusion I drew from this assignment was that both the analysis method are correct in diagnosing the transformer with thermal fault. For temperatures involved Rogers ratio method suggestions are deemed accurate compared to that of Duval Triangle. Considering the results, the transformer can continue normal operation but the sampling interval should be reduced to quarterly or monthly depending on the state of the transformer. Refer to Appendix B for further comments and analysis on this assignment.

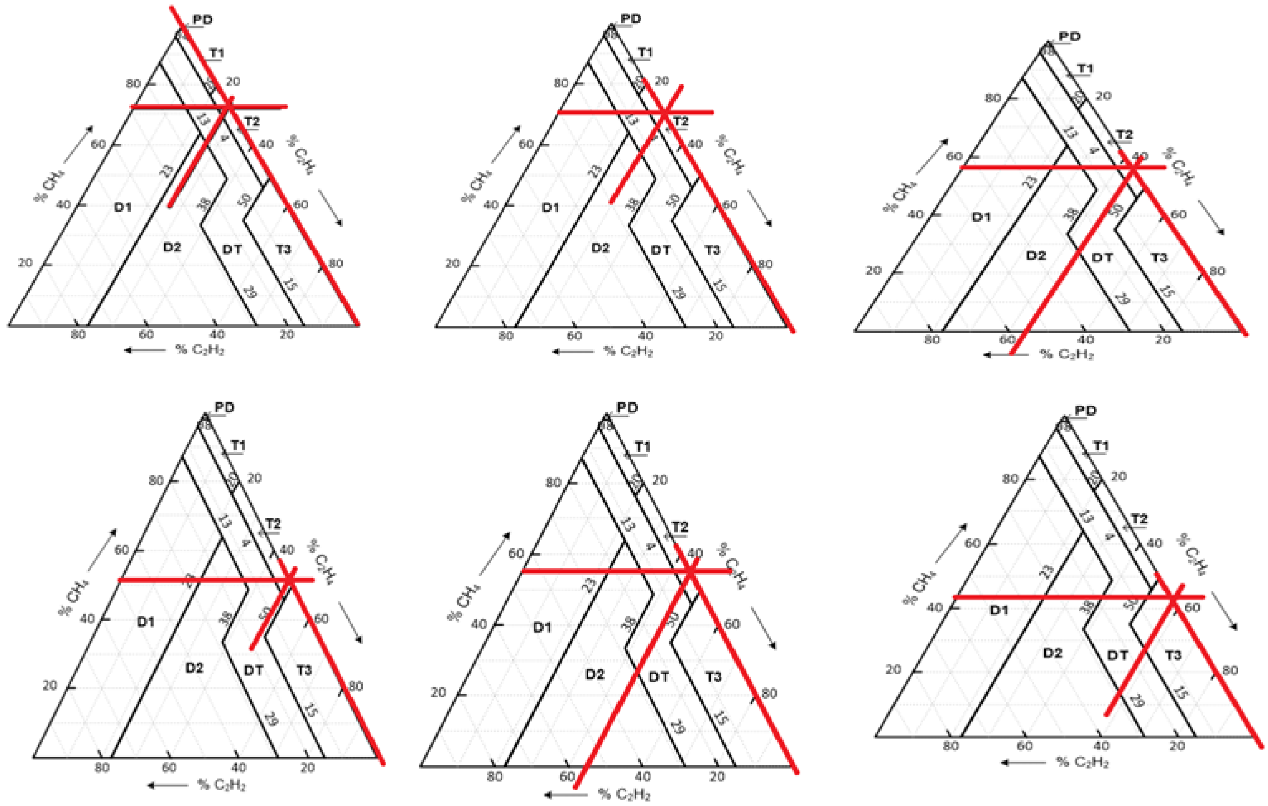

Figure 6: Duval Triangle method selected samples plots

Sample date	CH_4	C_2H_6	C_2H_4	C_2H_2	Fault level
2013/11/07	26	51	11	0	
2014/05/06	42	82	17	0	
2014/11/04	49	96	20	0	T2: thermal fault > 300°C, ≤ 700°C
2015/05/05	81	127	44	0	T2: thermal fault > 300°C, ≤ 700°C
2015/11/04	100	146	62	0	T2: thermal fault > 300°C, ≤ 700°C
2016/05/05	128	193	80	0	T2: thermal fault > 300°C, ≤ 700°C
2016/11/02	135	188	90	0	T3: thermal fault > 700°C
2017/05/04	140	228	94	0	T2: thermal fault > 300°C, ≤ 700°C
2017/11/01	177	243	104	0	T2: thermal fault > 300°C, ≤ 700°C
2018/05/03	201	286	136	0	T3: thermal fault > 700°C

Figure 7: Duval Triangle method results

4.3 Evaluation Criteria for 240-59083215

This was a group assignment issued to the electrical engineering EiT student including me. On this task, we were provided with the specification for permanent online moisture removal systems for use on power transformers and reactors, from this document we had to come up with the credible evaluation criteria with a scoring method. The document was for allowing the Eskom HV plant to select the best candidate from the bidders' list.

My greatest contribution to this assignment was the ability to thoroughly do my research and have the ability to elaborate on the assignment while ensuring every team player register what is required. This included verbal and written examples ensuring they get the picture of what needed to be done. The subsections below explain the knowledge I obtained from my research and how I applied it towards the successful completion of the assignment.

4.3.1 ***Schedule of Compliance*** The schedule of compliance is a list of requirements that are stipulated on the specification document, it has mandatory requirements that act as an early screening evaluation stage to determine whether all critical criteria and functionality are met. On this compliance sheet, there are usually three columns, for "yes" or "no" regarding compliance of given requirement and comments column. For every requirement that the bidders comply with, they have to provide supporting documents as proof that will later be used on the desktop evaluation. This compliance document allows the evaluation team to check if a bidder stands a chance before the beginning of the desktop evaluation. So the bidder has to comply with all the mandatory requirements to qualify for desktop evaluation. Appendix C showcases the schedule of compliance I created for this assignment.

4.3.2 ***Desktop Evaluation*** The desktop evaluation assesses the submitted schedule of compliance documents in detail and a percentage score is awarded to the respective bidder. The are many rules that control the evaluation procedure, the following are rules I selected from different sources that shall be imposed on the evaluation procedure:

1. For the bidder's schedule of compliance submission to be compliant it must meet all mandatory requirements and score a minimum requirement set by the evaluation team (usually 80%) on the desktop evaluation.
2. The physical evaluation on the bidder is only carried out if the desktop evaluation is passed.
3. In a case where the bidder passes the desktop evaluation but the tested equipment fails the demonstration, then that particular bidder product will be considered non-compliant with the Eskom requirement.
4. All bidders that pass the physical evaluation will be evaluated against each other (cost, maintenance, reputation, e.t.c)

Appendix D section 2.2 outlines the desktop evaluation criteria with the scoring method that I created.

4.3.3 ***Physical Evaluation*** Since desktop evaluation involves the paper design, the physical evaluation provides the testing and evaluation of the final prototype provided by the bidder. It is not guaranteed that the developed equipment outcomes to be as designed. In this phase, the equipment is tested against the requirements for verification. A physical evaluation is also known as factory evaluation. Similar to desktop, this evaluation criterion has the scoring method as well. Based on this criterion, the tender is awarded to the bidder who passed this evaluation and managed to satisfy all mandatory requirements. In cases where there are 2 or more bidders that managed to pass the physical evaluation, other factors will be considered to choose the best candidate, such as cost, maintenance, quality, etc.

Figure 8 below showcases the tender evaluation process flow. The input to the process is the list of bidders and the outputs will be a successful bidder if available and failed bidders comply with requirements.

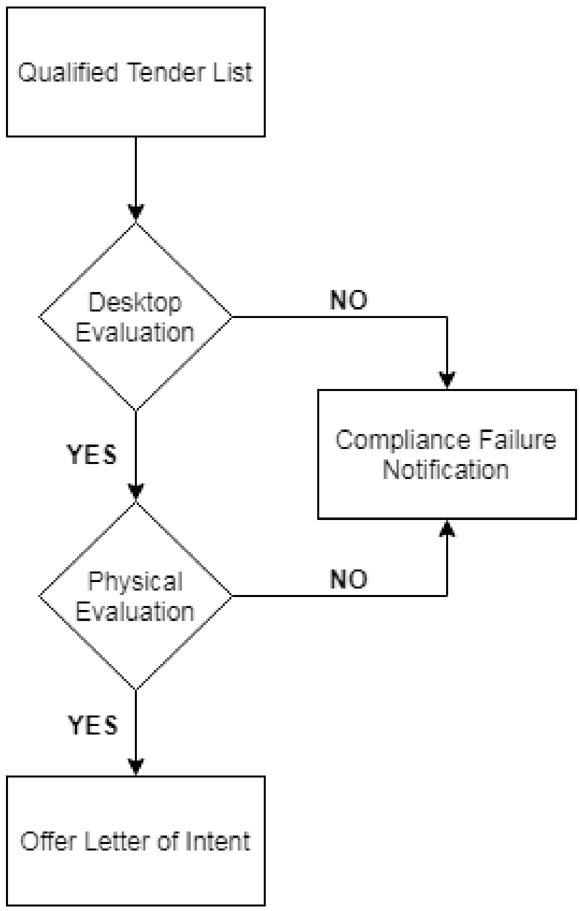

Figure 8: Tender evaluation criteria process

4.4 ***Transformer Failure Investigation***

There was a failed power transformer (132kV4/33kV-800MVA) at Emalahleni district in Mpumalanga province. I was tasked with the other EiT student to observe the failed transformer, note down important information then compile the gathered information to try to deduce what caused the failure to that transformer for learning. This site visit also allowed me to eye witness the substation equipment and how the switching devices are linked together to protect the transformer. Figure 9 (a) showcases the failed transformer and (b) showcases the HV equipment (circuit breaker, CT, VT, power transformer).

4.4.1 ***Gathered Information*** Upon inspecting the transformer in the presence of the substation chief technician the following information was obtained:

1. Two of the three secondary bushings broke-off.
2. PRV tripped
3. The power transformer tank was ruptured at the bottom and the oil spilled out at that opening.
4. The live wire from the bushing to the transformer winding was arcing with the top of the transformer tank.

To arrive at the root cause of the transformer failure I used the 5 why analysis with the finding I recorded on the site visit. The transformer tank ruptured at the bottom due to the high pressure that was inside the tank (pressure increases with depth inside a fluid container). The PRV also tripped indicating the pressure was beyond limits. The pressure inside this transformer is due to the arcing between the live wire (from bushing to the winding) and the top of the tank inside the transformer. This implies the arcing involved a high amount of energy that was enough to heat the oil and chemically transform it into dissolved gases (methane, ethane, acetylene, etc.). With continuous arcing leading to continuous gas generation, the force exerted by the gases is greater and eventually exceeds what the tank can withstand hence the rupture.

The DGA results of the previous transformer inspection showed that transformer still healthy and can continue with service. During the period of the transformer failure, the records showed that the was no rain and lightning in that area. The cause of the arcing may be due to the overloading of the power transformer. The transformer was supplying a certain firm in that area. The correctness of the analysis I made can be verified by the recorded time series data of power consumed by the firm.

4.4.2 ***Safety Measures at Substation*** Eskom personnel do follow safety and common interlocking rules. The following are safety measures that were considered on site:

- No one was allowed to enter the substation before wearing the PPE.
- Electrical engineers were no allowed to enter inside the perimeters of the substation before the arrival of the technicians.
- Technicians ensured hook-up at height was obeyed when the transformer top was opened to observe inside it.
- The transformer was correctly isolated and grounded.

(a) failed transformer

(b) Substation HV equipment

Figure 9: Emalahleni substation site visit

5. CONTROL & AUTOMATION

Control & Automation is a unit within PTM&C department that is responsible for research of new technologies that are beneficial to the SCADA system and make sound decisions on the latest software and hardware required. Through the SCADA system, they can monitor and control electrical systems both locally (HMI's within the substation) and remotely (NCC). It allows tedious, repetitive, and human error-prone activities to be automated thus increasing efficiency, productivity, and protecting equipment from damage.

*5.1 **Interlocking Tool***

Interlocking is a set of protocols that needs to be true to perform a specific function. This project aims at developing the interlocking tool that will be applied to the HV plant that will ensure the interlocking rules are met to safely operate a specific device within the substation.

Some of the objectives of the tool include the protection of humans from incorrect switching operations and ensuring national grid stability while protecting other involved equipment as well. On this project, I have been added as a resource to learn and assist my coach. This project so far has allowed me to witness the project life-cycle within Eskom. This includes registration of BOC's and writing of URS.

The project is still in progress, the design phase has been completed. The subsections below give the outline of the task within the project plan that I was allocated to do.

5.1.1 ***Generic Interlocking Rules*** On this task, I had to gather two remaining business cases of the three substations. After going through those documents I had to compile generic interlocking rules that can be applied to different Eskom substations.

5.1.2 ***Process Flow*** In this activity of the project, I was tasked to create the process flow for the interlocking tool. This process will be used to verify the correctness of the tool before commissioning. This process flow also shows what should happen when the tool fails at the given stage of the test. Figure 10 showcases the interlocking tool process flow diagram.

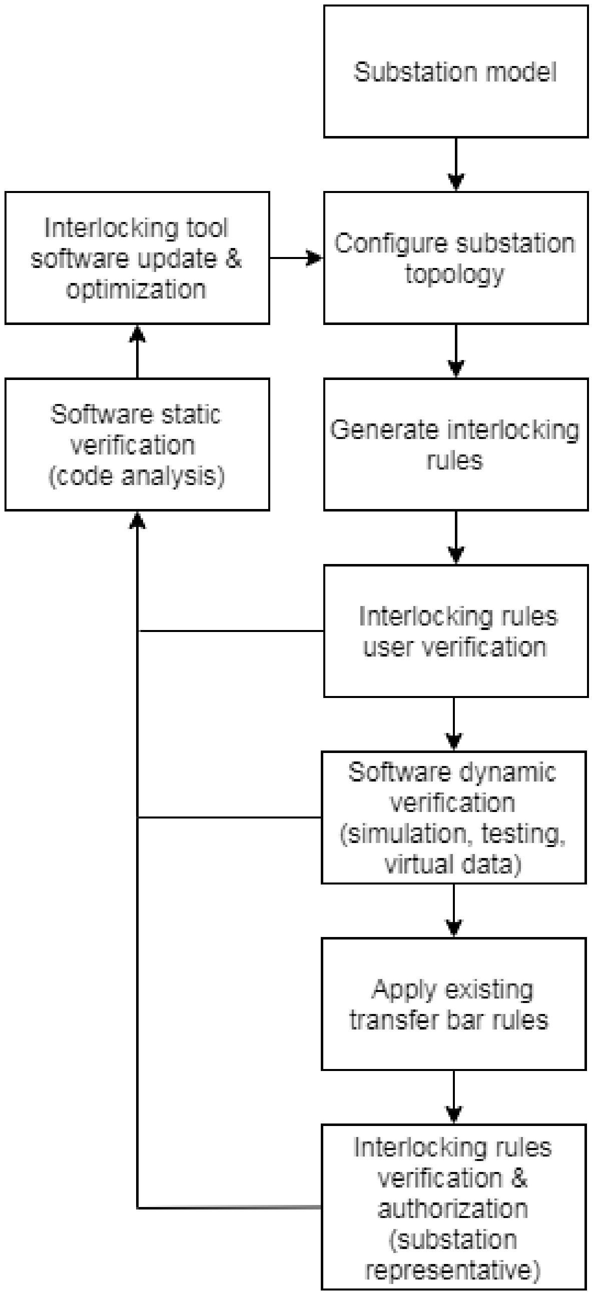

Figure 10: Interlocking tool process flow

6. SUMMARY

6.1 Extent of Training Activities

The training activities that I participated in during the past 11 months are summarised in Table 3 below.

Table 3: Summary of training activities including level of responsibility and the ECSA outcomes

Department	Description	Level of Responsibility	ECSA Outcomes
HV Plant	Introduction to susbstation equipment	Being Exposed	
	Compiled an Evaluation Criteria for an online moisture removal system for use on power transformers and reactors	Participating	6, 8
	Emalahleni failed transformer analysis	Being Exposed	4
	Diagnosis of Leseding substation transformer (**Leseding No1 Trfr Bay 400kV -132kV -22kV Trfr**) using dissolved gas analysis	Participating	4, 6, 8
Control & Automation	Development of generic interlocking rules document	Assisting	
	Development of interlocking tool process flow	Assisting	

6.2 Value Added During Training

The Coronavirus pandemic brought a huge negative impact to EiT program I had to follow, but even under such circumstances, there have been opportunities for me to contribute value to Eskom. This include:

1. Compiling evaluation criteria for an online moisture removal system for use on power transformers and reactors.
2. Collection of transmission power transformer nameplate photos for 3 different grids to be stored in the Eskom database.
3. Diagnosis of gassing transformer using DGA.
4. Assisting on the interlocking tool project.

I also got the opportunity to work with professional engineers. Interactions with these experts improved my work ethics and my way of thinking.

6.3 OHS Act

OHS act addresses key responsible that employers and employees have in the workplace towards each other and themselves respectively. I have witnessed that Eskom is committed to ensuring the safety of people and the environment by making certain that any project taken guarantees safety. Eskom further implemented the life-saving rules to include the OHS act in everyday business. These rules are as follows:

1. Open, isolate, test, ground, bond, and/or insulate before testing.

2. Hook up at heights.
3. Buckle up.
4. Be sober (100%).
5. Have a valid working permit.

6.4 Leadership Opportunities and Networking Achieved

The majority of the tasks I participate in was not group work with other students, but the task of creating the evaluation criteria for the online dryer allowed me to take leadership on this assignment, the details of this assignment were discussed in section 4.3. The feature of the EiT program being rotational to various departments of PDE has allowed me to meet different experts who were all willing to share more about the role they play within Eskom and how their respective departments contribute to the Eskom daily business.

6.5 Pro-activity and Innovation

In the first month of my training at the HV plant, I did not have a mentor or a coach at that time. I spent the first day doing nothing, on the next day and moving forward, myself and one of the EiT students decided to introduce ourselves to our expert colleagues, we asked them about the roles and contribution to the business. We requested tasks they can issue to us and also requested to accompany them whenever they go to the site.

The diagnosis of the power transformer using DGA consumed a lot of working hours, I observed that the process is the same, the input is just the concentration of dissolved gases and the output is the condition of the transformer. I noticed that the automation of this diagnosis process can save a lot of time and allow the person performing that particular task to focus on other activities, thus increasing the efficiency of work done on that particular day. I was aiming to develop a simple application that will read the provided gases CSV file and produce an output file with all the details of the transformer diagnosis, this implies algorithms for DGA methods aforementioned will be embedded to this application code. However, this communication did happen between my mentor and me at the HV plant as we lost contact along the way.

6.6 Highest Level of Responsibility

The highest level of responsibility I had was participating, I am currently assisting with the development of the interlocking tool.

6.7 Awareness of Professionalism

Across the EiT program, I completed ethics and fraud awareness training. At the Control Automation, I have to submit the weekly plan and progress on the planned work on Fridays. From all these I learned that as an engineer I have to be honest especially with the working hours since I am working from home, I have to respect my colleagues. I have to follow and apply work-related standards. Ensure the safety of people and the environment, never use Eskom software for my personal use or solve Eskom problems with unlicensed software.

7. CONCLUSION

The past 5 months at Control and Automation has shown me how projects are accomplished. I looking forward to the next stage of my training, which will be being involved in the development of the interlocking tool.

References

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[2] H. Malik, R. Jarial, and H. Rai. "Fuzzy-logic applications in transformer diagnosis using individual and total dissolved key gas concentrations." *International Journal of Latest Research in Science and Technology*, vol. 1, no. 1, pp. 25–29, 2012.

Appendix

A Summary of DGA methods

A1 Individual and Total Dissolved Key-Gas Concentration Method

1. Used for detecting faults
2. Independent & assumes no previous tests made
3. Uses the highest level individual gas or TDCG
4. TDCG = condition 3 but a specific gas = condition 4 then transformer = condition 4

status	Operation
Condition 1	Satisfactory (investigate excessive gases)
Condition 2	Possible fault (investigate excessive gases)
Condition 3	Excessive decomposition of cellulose/oil (take frequent samples for testing)
Condition 4	Excessive decomposition of cellulose/oil (continuing operation may lead to failure)

status	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	CO	CO_2	TDCG
Condition 1	100	120	35	50	65	350	2500	720
Condition 2	101-700	121-400	36-50	51-100	66-100	351-570	2500-4000	721-1920
Condition 3	701-1800	401-1000	51-80	101-200	101-150	571-1400	4001-10000	1921-4630
Condition 4	>1800	1000	>80	>200	>150	>1400	>10000	>4630

Figure 11: Individual and Total Dissolved Key-gas Concentration method summary

A2 Rogers Ratio Method

1. Fault analyzing not fault detecting
2. Uses 3 ratios
3. Denominator = gas detection limit if gas (denominator) = 0
4. Derived from Doernenburg ratio method
5. Accuracy drops with gas used < 10x chromatograph can detect

Code Range of Ratios	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	Detection limits		
				x1	x10	gas
< 0.1	0	1	0	1 ppm	10 ppm	C_2H_2
0.1-1	1	0	0	1 ppm	10 ppm	C_2H_4
1-3	1	2	1	1 ppm	10 ppm	CH_4
>3	2	2	2	1 ppm	10 ppm	C_2H_6
				5 ppm	50 ppm	H_2

case	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	Suggested Fault Type
0	0	0	0	No fault
1	1	1	0	Low energy PD
2	1	1	0	High energy PD
3	1-2	0	1-2	Low energy arcing, sparking, discharge
4	1	0	2	High energy discharge, arcing
5	0	0	1	Thermal fault <150°C
6	0	2	0	Thermal F 150-300°C
7	0	2	1	Thermal F 300-700°C
8	0	2	2	Thermal fault >700°C

Figure 12: Rogers Ratio method summary

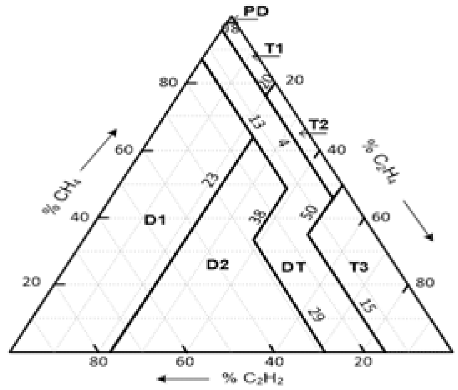
A3 Duval Triangle Method

1. Fault analyzing not fault detecting
2. Uses 3 gases percentage contributions
3. The analysis depends on past results
4. Highly accurate
5. Fault is three lines intersection

$$\%CH_4 = 100 \times \frac{\Delta CH_4}{\Delta CH_4 + \Delta C_2H_2 + \Delta C_2H_4}$$

$$\%C_2H_2 = 100 \times \frac{\Delta C_2H_2}{\Delta CH_4 + \Delta C_2H_2 + \Delta C_2H_4}$$

$$\%C_2H_4 = 100 \times \frac{\Delta C_2H_4}{\Delta CH_4 + \Delta C_2H_2 + \Delta C_2H_4}$$



Zone	Fault Indication
T1	Thermal fault ≤ 300°C
T2	Thermal fault > 300°C, ≤ 700°C
T3	Thermal fault > 700°C
D1	Low energy discharge (sparking)
D2	High energy discharge (Arcing)
DT	Combination of thermal and electrical faults
PD	Partial discharge

Figure 13: Duval Triangle method summary

A4 Requirements to use DTM

1. A problem with the transformer should exist
2. One of the hydrocarbons or hydrogen should on condition 3 or
3. At least one individual gas must be at L1 level or above
4. ABB (and the gas generation rate at G2)

Gas	L1 limit	G1 limits (ppm/month)	G2 limits (ppm/month)
H_2	100	10	50
CH_4	75	8	38
C_2H_2	3	3	3
C_2H_4	75	8	38
C_2H_6	75	8	38
CO	700	70	350
CO_2	7000	700	3500

method	% correct diagnosis	% unresolved diagnosis	% wrong diagnosis
KGM	42	0	58
RRM	62	33	5
DTM	96	0	4

Figure 14: Duval Triangle method requirements

Diagnosis of a Gassing Transformer using DGA

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INTRODUCTION

This paper present the detection and analysis of faults on the Leseding (**Leseding No1 Trfr Bay 400kV - 132kV - 22kV Trfr**). This paper should be used in conjunction with the presentation slides that will hand in with this paper.

1. DISSOLVED GAS ANALYSIS

1.1. Fault Detection

For fault detection of the transformer, the *key-gas* method and *individual & total dissolved key-gas concentration* method are used to detect if the transformer has faults. The conditions required to apply this aforementioned methods are detailed explained in the presentation slide.

1.2. Fault Analysis

Rogers ratio method and *Duval triangle* method are used to fully analyze the type of fault that is occurring inside the transformer and also shows the severity of the problem. These methods are not used for detecting faults thus they should only be used for analyzing the faults only if the existence of fault in the transformer has been detected by the detection methods aforementioned. Success criteria required to use this method has been stipulated in the presentation slides as well as how to apply them.

2. RESULTS

2.1. Fault Detection

It was challenging to detect the faults inside the transformer using the *key-gas* method. Since the method uses 4 charts to detect faults, all the charts plotted for every sample did not match any of the standard charts by the *key-gas* method.

Using *individual & total dissolved key-gas concentration* method, it was possible to detect for all the samples as either positive or negative. No fault was identified on the first sample. The 2nd sample until 8th sample showed that the transformer to be on condition 1 which shows that the transformer is operating satisfactorily but there were gas that were beyond their limits thus the method suggested that further investigation is done on those gases. The 9th and 10th

sample showed the transformer to be on condition 2 which shows that fault may be present since the total dissolve combustible (TDCG) exceed the specified limit, it also suggested that the individual gases exceeding their limits have further investigation as well.

2.2. Fault Analysis

All the rules required to perform the Rogers ratio analysis were applied correctly considering its requirements as well. The 1st sample was not tested since it was detected to be normal. The method showed the 2nd and 3rd samples to have no faults. The 4th until 10th samples were analyzed to be thermal faults with the temperatures of 150°C-300°C. The method further suggested that the problem is with the cellulose insulation, which will release CO_2 and CO.

Analyzing the Duval triangle method, the 2nd sample was not tested as it did meet the requirement of the method. The 3rd - 6th, 8th and 9th samples were found to be thermal faults within the temperatures of 300°C-700°C. The 7th and 10th samples were found to be thermal faults with temperatures greater than 700°C.

The ratio of the CO_2/CO was also used to check support the other methods. IEC 60599-2007 state that if the ratio is less than the value of 3 then there is excessive paper degradation due to the overheating of the conductor, it further states that if the overheating involves the oil, then the ratio will be greater than 10. The results shows CO_2/CO ratio of the 1st and 2nd samples to be 1.581 and 0.804 respectively. The 10th sample is found to have the ratio of 1.858.

The level of oxygen and the moisture reading were also studied. It was observed from the samples data that level of dissolved oxygen within the oil was decreasing as the samples were taken every 6 months. The level of moisture was found to increasing inside the transformer.

3. DISCUSSION AND ANALYSIS

Both the Rogers ratio and Duval triangle method diagnosed the transformer to be experiencing thermal fault, therefore it can be concluded that the transformer is under thermal stress. Since the thermal fault can occur on oil/cellulose the Rogers ratio method suggested that the faults are within the cellulose. This suggestion by the Rogers method tally with the result CO_2/CO ratio were it was observed that ratio only went below 3 in some samples and never went beyond 10 thus the using IEC 60599-2007 it shows that the fault is due to cellulose overheating caused by the overheating conductor. When the cellulose is overheated, it release hydroxide (OH^-) that combines with oxygen to form moisture. The level of oxygen was witnessed depreciating from the samples which moisture was increasing thus this shows the aforementioned behavior was taking place.

It has been proven that the presence of high concentration of dissolved oxygen within the oil halves the life of the cellulose insulation and that the level of oxygen should not exceed 3000ppm. The level of oxygen was exceeding the limit at the beginning, thus this oxygen actual increases the oxidation of the cellulose as well and speed up the aging of the cellulose insulation.

4. RECOMMENDATIONS

- The transformer can continue operation under exercised caution.
- The root cause of the problem should be found and eliminated
- The samples of the transformer for testing should be taken quarterly since the TDCG shows the system to be at condition 2 with TDCG generation rate (ppm/day) less 10.

5. CONCLUSION

Detection of the faults on the transformer was performed. After faults were detected, the analyzing of the faults was performed. The transformer was found to be experiencing thermal faults. It was recommended that the transformer continue service under exercised caution and increase the sampling frequency of the transformer.

Compliance to Technical Specification for Permanent Online Moisture Removal System for use on Power Transformers and Reactors

Tenders are required to fill the entire schedule specifying their compliance to every item of the technical specifications. The comment section is included to comment on the compliance or non-compliance to items. This document is cross-reference with the Specifications for permanent online moisture removal system for use on power transformers and reactors thus they must be used in union. Supporting documents should be provided for evidence of compliance.

Technical Specification Items	Compliance		Comment
	YES	NO	
4.1 General			
4.2 Functional Requirements			
4.3 Alarming and Communication			
4.3.1			
4.3.2			
4.3.3			
4.3.4			
4.3.5			
4.3.6			
4.4 Site Installation Requirement			
4.5 Replacement Filter Element			
4.6 Corrosion Protection			
4.7 Electrical Connection and Termination Boxes			
4.8 Nameplate Information			
4.9 Training			
4.10 Documentation and Packaging			
4.11 Technical Evaluation and Final Approval			

D Evaluation Criteria

2.2. Desktop Evaluation

This section defines the scoring method that will be used to award prospective supplier's a score based on their submitted schedule of compliance. Each requirement score will be credited by the tender issuing company considering the suppliers response and supporting material for evidence. The scoring method that will be used is shown in table 1 below.

Table 1: Desktop evaluation scoring method for the schedule of compliance

ASSESSMENT	DESCRIPTION	SCORE	%
Excellent	• satisfy technical requirement(s) with evidence from supporting material. • There are no calculated technical risks in reaching the technical requirements.	5	100
Good	• satisfy the technical requirement(s) with risks that can be accepted • presence of supporting material.	4	80
Limited	• satisfy technical requirement(s) in most aspects and fail in some. • has unacceptable technical risks.	3	60
Inadequate	• fails to satisfy technical requirement(s) in most aspects and satisfy in some. • has unacceptable technical risks. • no supporting material for evidence provided	2	40
Not eligible	completely fails to satisfy the requirements	0	0

Table 2: Qualitative evaluation - schedule of compliance

Criteria	Section	% Weight	Weighted Score
Functional Requirement	B1	50	
Alarming and Communication	B2	40	
Replacement Filter Element	B3	10	
Total		**100**	

B1	**FUNCTIONAL REQUIREMENTS**

ITEM NO	DESCRIPTION	UNIT	CRITERIA	SCORE
B1.1	Does the manufacturer comply with functional requirements stipulated in the specifications?	% compliance	>90%	5
			70-90%	4
			30-70%	2
			<30%	0
Functional Requirements **(maximum points: 5)**			Score	
FUNCTIONAL REQUIREMENTS **(Section weight: 55%)**			Weighted Score = **(Score)*(50/5)**	

B2	**ALARMING AND COMMUNICATION**			
ITEM NO	**DESCRIPTION**	**UNIT**	**CRITERIA**	**SCORE**
B2.1	Design shows the availability of signals for interrogation via communication interface and a display screen for their display	% compliance	>90%	5
			70-90%	4
			30-70%	2
			<30%	0
B2.2	Communication interface design comply with requirements required	% compliance	>90%	5
			70-90%	4

			30-70%	2
			<30%	0
B2.3	Manufacturer designs shows communication with the device to be possible via the media stipulated in the specification	% compliance	>90%	5
			70-90%	4
			30-70%	2
			<30%	0
Alarming and communication **(maximum points: 15)**			Score	
ALARMING AND COMMUNICATION **(Section weight: 40 %)**			Weighted Score = **(Score)*(40/15)**	

B3	**REPLACEMENT FILTER ELEMENTS**			
ITEM NO	**DESCRIPTION**	**UNIT**	**CRITERIA**	**SCORE**
B3.1	Are filter elements used in the design freely available in South Africa?	% compliance	Yes	5
			No	0
B3.2	Is the element of the filter cartridge system used in the design disposable?	% compliance	Yes	5
			No	0

Replacement filter elements **(maximum points: 10)**			Score	
REPLACEMENT FILTER ELEMENTS **(Section weight: 10%)**			Weighted Score = **(Score)*(10/10)**	

2.3. Physical Evaluation

A physical evaluation is conducted after a supplier has met the requirements of the desktop evaluation criteria. The criteria for the physical evaluation are point scored. An assessment of 'Yes' equates to 5 (five) score points. An assessment of 'No' equates to 0 (zero) score points. For the supplier's physical evaluation to be compliant it must score a minimum of 90 points. The criteria are:

EVALUATION ASPECT	**YES/NO**	**SCORE**
ALARMING AND COMMUNICATION		
Available signals		
Percentage of saturation of the cartridges		
Moisture in paper as percentage		
Water ppm value into the systeem		
Water ppm value out from the system		

Error code from a particular fault		
Communication interface		
Device provides data/statuses through IEC 61850 protocol?*		
Is remote access and integration possible with TCP/IP protocol using http(s) based web interface?*		
Is it possible to configure, diagnose and interrogate the system using a web interface?		
Downloading of files possible using FTP?		
Communication medium		
Multimode Fibre Ethernet port (100BaseFX) with Duplex LC connector?*		
Copper ethernet (100BaseTX) with RJ45 connector?*		
GPRS/GSM Modem (extra)?		
5GHz wireless (extra)?		
LEDs		
Green daylight LED for normal operation?		
Red daylight LED for indication of saturated filter cartridges?		
Blue daylight LED for problems detected with the system itself?		
Local indication		

Display screen displaying the minimum signals (see 4.1)?*		
Relay outputs		
2 potential free contact (alarm relays) for main cartridges saturated (N/O and closes when cartridges are 90% saturated)?		
2 potential free contact (alarm relays) for system fault (N/O and should close if any fault found in the system)?		
Relay has a make and carry current of 1A @ 250Vdc?*		
Relay can continuously carry 1A?*		
Relay break (Inductive L/R = 40ms) at 10W @ 250Vdc?*		
Comment/s:		**Total Score:**
SITE INSTALLATION REQUIREMENTS		
Is welding done in the correct manner (i.e no welding is performed on the transformer tank)?		
Is the unit free standing and self-supported?*		
Is stainless steel brackets, fittings, pipes and fasteners used?		
Is the system effectively earthed to the substation earth-mat by means of one 3 mm x 50mm flat copper strip?*		
Are pipes adequately secured and mechanically protected to prevent any damage during normal maintenance activities?		

Comment/s:		**Total Score:**
REPLACEMENT FILTER ELEMENTS		
Are replacement filter elements supplied dry?*		
Moisture is not released back into the oil when filters are saturated?*		
Is waste oil limited to a maximum of 5litres per filter system?*		
Comment/s:		**Total Score:**
CORROSION PROTECTION		
Is there use of non-corrodible materials, by avoiding the contact of dissimilar metals?		
Are all fasteners made up of stainless steel?		
Is adequate lubrication applied to all threaded areas of bolts, studs and screws?		
Comment/s:		**Total Score:**
ELECTRICAL CONNECTIONS AND TERMINATION BOXES		

System electrical circuits withstand an applied voltage of 2kV for 60 seconds?*		
Are termination boxes with IP 56 rating provided for electrical connections?*		
Are terminal boxes mounted to allow cable entry from the bottom?		
All terminals of spring loaded type?*		
Are terminal boxes mounted correctly as specified in section 4.7d?		
Are the relay contacts cabled to the Marshalling Kiosk by means of steel wired armoured cabling that is heat, oil and UV resistant?		
Is two pole circuit breaker t used for isolation at the point of supply?		
Is the main isolator label with black lettering and permanently engraved?		
Do the cables used comply with Eskom cable specification 240-56227443?*		
Comment/s:		**Total Score:**
DOCUMENTATION AND PACKAGING		
Are the original and fully detailed instructions for assembly, operation and maintenance of the system included with each system?		
Is the system securely packed and properly protected against damage and moisture ingress during shipping and storage?		

Is the standard test card bearing the manufacturer's serial number of the system included with each of the operating instruction manuals?		
Are the pipe openings suitably sealed?*		
Comment/s:		**Total Score:**