Andy Morin & Associates
PO BOX 16115
Bellemont, AZ 86015

Boyd Davis
Sr. Electrical Engineer
Cholla Power Plant
4801 Frontage Road
Joseph City, AZ 86032

Dear Mr. Davis,

On behalf of Northern Arizona University, the Electrical Engineering Department, and our team, we would again like to thank you and APS for making a capstone project available. This endeavor gave our team an invaluable opportunity to advance our education through researching a generation step up transformers at Cholla. This research, and the project, culminated on April 26th 2013 when we presented our findings at NAU's undergraduate symposium. The PowerPoint and poster presentation were well received and informative to all in attendance.

Since our last status report, our team has analyzed the data we received and used the insight collected during the internal transformer inspection to compile a condition assessment of the transformer.

While much of this report consists of information you have already reviewed, please take note of the new content that has been added. A new summary of the document is located on page 1. Our system diagram has been changed and it is on page 3. The testing section has been updated to show testing and analysis from three different time frames. The new information for this section starts on page 19. A closing remarks section has been added. This part includes our condition assessment as well as some takeaways from the project; it begins on page 22. Our budget has been updated to show our total cost of $781.00. This breakdown is on page 23. The team's updated schedule, with hours worked, is located on page 24. Finally the PowerPoint we presented starts on page 26. This information will also available online at:
http://www.cefns.nau.edu/interdisciplinary/d4p/EGR486/EE/13-Projects/Transformer/index.html

Our team learned and experienced many things from this project. An illustration is that a good design process allows for creativity and ingenuity. Moreover, the process creates a structure that establishes a realistic way to achieve complex goals within a deadline. Because of this project, our team was able to explore and create a unique process to reach our establish goals. In addition, by witnessing firsthand the planning of the outage, the outage itself, and the internal inspection of the transformer, our team gained unique knowledge that was valuable to our education, and will continue to be valuable in our careers no matter the field we peruse. Thank you again for this opportunity.

Very Respectfully,

Andy Morin, Scott Lederhos, Kyle Wiedeman, Kenny Elgin, &
Richard Barnes

Northern Arizona University

APS Transformer Final Report

Cholla Unit 2 Generation Step Up XFMR

Richard Barnes
Kenny Elgin
Scott Lederhos
Andy Morin
Kyle Wiedeman

Contact Information
Phone:
480-703-4616

Email:
Atm47@nau.edu

Mailing Address:
PO Box 16115
Bellemont, AZ 86015

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Executive Summary

During recent Dissolved Gas Analysis tests of the Cholla Unit 2 Generation Step Up Transformer there have been certain gasses present which may be indicating the end of life for this transformer. APS scheduled a planned outage in March of 2013 to have a visual inspection of this transformer performed. Prior to the inspection our team was asked to perform research and analyze data, so that we can give a reasonable prediction of the transformers condition.

As a team, we have continued researching oil immersed transformers and how to make an accurate condition report. The main focus of our research the past few months has been focused on Dissolved Gas Analysis. This type of analysis is excellent for our project because the gas samples can be collected while the transformer is online and we are continually receiving the necessary data. The Dissolved Gas Analysis techniques which are discussed are Key Gases, Dornenburg's Ratio, Rogers Ratio, and Duval's Triangle. Once we became familiar on how each of these techniques provides viable information we applied them to our project as a vital condition assessment tool.

In addition we have added our analysis of the oil data provided to us by APS. This includes water content, oxygen, and thermal imaging analysis. As mentioned before we have also included Dissolved Gases to our analysis.

Also, we have included an updated schedule containing our workload during this final semester. The Gantt chart is broken up by each team member so that it is clear to see who is responsible for each task. The second portion of the schedule shows when APS took the transformer offline.

Our only cost to complete this project was for travel, meeting expenses, and a text book. We spent a total of $781.00 on this project. APS and our team verbally agreed to a $2000 budget for the completion of this project and we were well within this limit. A section has been included with a breakdown of our team's budget.

The last new portion is our team's final power point presentation, which we presented at the undergraduate symposium on April 26th, 2013. This presentation is a broad overview of our entire project with a brief conclusion of our assessment on the transformer.

Project Definition

You have requested that our team analyzes the current condition of the Cholla Unit 2 Generation Step Up transformer. As part of APS's routine maintenance for the transformer, you check for dissolved gasses within the oil of the transformer. In oil samples taken during the summer of 2012 there have been certain gasses present which indicate possible degrading of the transformer's health. Along with these gasses found in the oil, two of the four oil cooling pumps have also been taken out of service due to high vibrations. These concerns have led to a planned outage on the transformer during the spring of 2013. During this outage the transformer will be drained of its oil so that the failed pumps can be replaced. An internal visual inspection will also be performed during this outage.

It is important to predict a failure before it happens with this transformer, because a transformer of this size can take over 9 months to acquire a replacement. There is no spare transformer, which is ready for service, to use in its place. This means that unit 2 at Cholla would be offline for several months. Having a unit which is unable to generate power for several months would result in a huge economic loss for APS.

Our team is to research predictive analysis, reasons for failure, and a variety of tests which will help you better understand the current condition of your transformer. The reasons for failure portion of our research will include case studies of previous failures. These case studies may show a correlation between the problems in other transformers before they failed and the current problems with the transformer at Cholla. The several tests which will be included in our research will assist us with predictive analysis, and allow our team to better understand the current health of the transformer. These tests will include oil testing that can be done with the unit online and a recommendation of electrical test that can be performed after the unit is not in service. Our final product will be a report to APS which will assist you on determining the current condition of this transformer as well as additional recommendations for future monitoring.

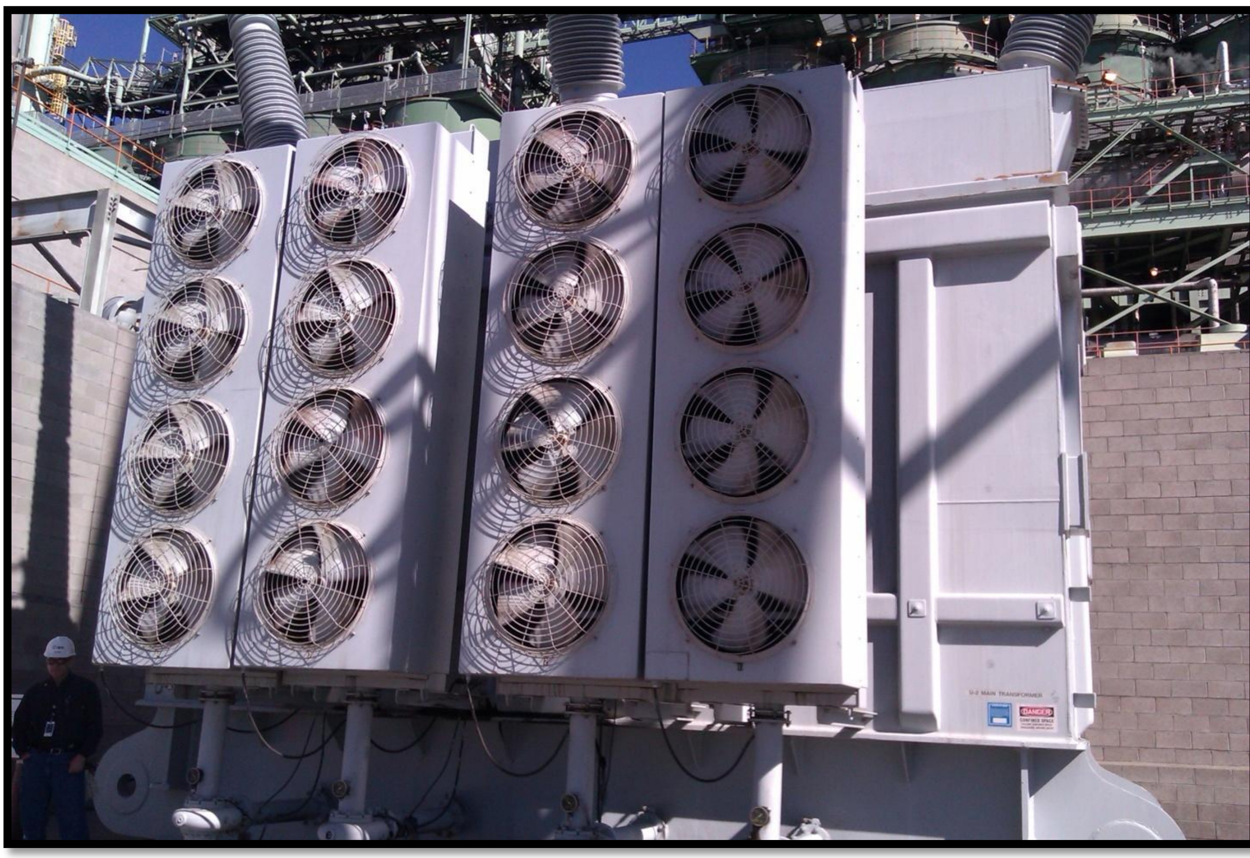

Figure 1
Unit 2's Generation Step-up Transformer

System Diagram

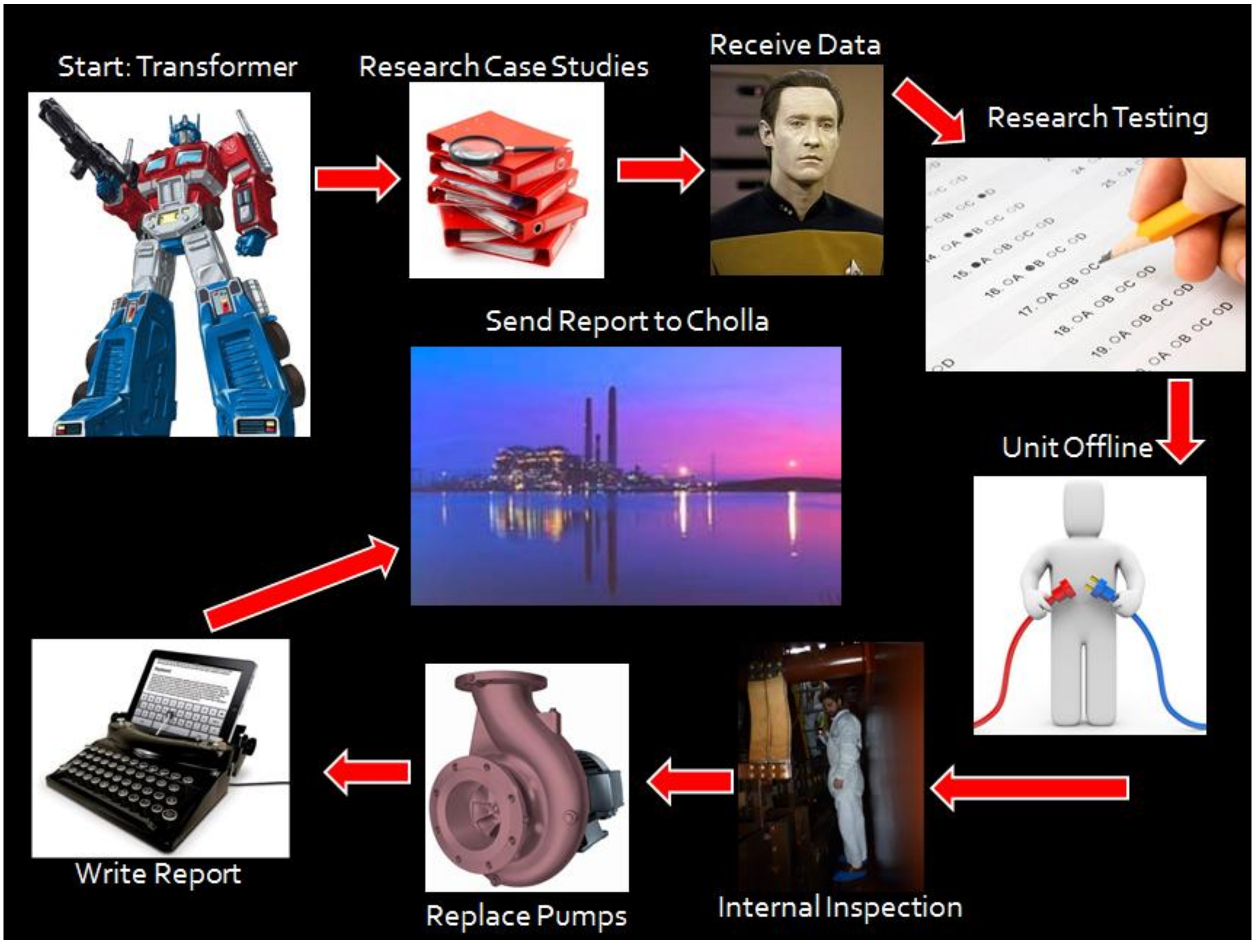

Figure 1
System Diagram

Research Survey

In the research conducted by the team we found common causes for transformers to fail. Insulation failures were the main cause of transformer failures in a study done by the Hartford Steam Boiler Inspection & Insurance Company [1]. There are four main reasons as to why insulation fails: moisture, acidity, heat, and oxidation [1]. As insulation ages it will naturally slowly breakdown [2]. Localized hotspots in a transformer will increase the premature aging of the insulation [2]. Overloading and a degraded cooling system will cause severe aging of the winding insulation. This type of failure is a typical end of life failure [2]. If a transformer is running abnormally hot and/or puts out less than normal voltage you can assume winding insulation failure causing windings to be shorted together [2].

Design, materials, and workmanship are the second leading cause of transformer failure according to the Hartford Steam Boiler Inspection & Insurance Company [1]. This type of failure includes situations like loose or unsupported leads, inadequate core insulation, poor brazing, loose blocking, improper connection of dislike metals, and improper tightening of bolted connections [1]. Loose clamping can result in arcing/sparking discharges which produce fine carbon contaminants everywhere, particularly on the top frame surface [2]. Also, loose clamping can cause the coil assembly to relax which can cause discharges and fine carbon contaminants inside the windings [2]. Oil contamination is also one of the top reasons for transformer failure [1]. The oil can get contaminated in storage, transportation, and while in the transformer [3]. Transformer oil mainly gets contaminated while in use inside the transformer. Paper insulation can dissolve in the transformer from electrical and thermal stresses [3]. The electric fields inside a transformer can cause conducting contaminants to move towards high field intensity, and develop a bridge [3]. This bridge can cause arcing, and a hotspot further breaking down the oil [3].

An investigation into failures claims that 17.32% of transformers fail because of lightning strikes [4]. These lightning strikes can produce extreme voltages that transformers cannot handle. In fact, the voltages can approach close to a million volts [5]. The impulse created by lightning causes large magnitude traveling waves that causes serious harm to the electrical and mechanical integrity of the transformer [6]. These failures could be a high magnitude overvoltage, a nonlinear distribution along the winding, which could make a high voltage between turns, or resonance/partial-resonance in the high voltage winding if they coincide with the excitation frequencies [7]. If the surge from the strike appears at the terminals "The transformer main insulation (the insulation between HV winding and LV winding, HV winding and core, or HV windings) will be threatened because of the large magnitude of the lightning surge. On the other hand, the insulation between turns at the beginning of the HV winding is often disproportionally more stressed because of the large potential gradient appearing in the initial voltage distribution. Similar to switching overvoltages and very fast transients, it is possible that lightning overvoltage may excite partial winding resonance in the transformer windings. The distance between the arrester and the transformer will determine the overvoltage magnitude at the transformer HV terminals [7]." Line-surges and external short circuits can cause the same type of damage as lightning strikes. Some companies have even started to categorize these surge types more than lighting strikes, because the strike was not "confirmed" even though it may have been suspected [1].

An overload is when a transformer's load exceeds its rated capacity. Overloading also causes a transformer to fail and will significantly reduce the transformers life-cycle [8]. Overloading also increases the deterioration of the transformer's insulation [8]. When determining overload practices, the top-oil temperatures should not be the sole guide used, because there are major differences between this temperature and the temperature of hot-spots within the transformer [8]. "The hottest-spot winding temperature is the principal factor in determining life due to loading. The temperature cannot be measured directly because of the hazards in placing a temperature detector at the proper location because of voltage. Standard allowances have, therefore, been obtained from tests made in the laboratory. The hottest-spot copper temperature is the sum of the temperature of the cooling medium, the average temperature rise of the copper, and the hottest-spot allowance. The hottest-spot allowance at rated load is 10 °C for transformers with 55 °C average winding temperature rise by resistance and 15 °C for transformers with 65 °C average winding temperature rise by resistance [8]." Overload has been said to account for 2% of transformer failures [6].

There are numerous tests that can be done to assess the health of a transformer. The majority of the oil tests can be done while the transformer is online by taking a non-invasive oil sample. Other electrical tests have to be done while the transformer is not in service.

Dissolved Gas-in-Oil Analysis

The Dissolved Gas Analysis test analyses oil samples from a transformer and helps predict which components that could be faulty. The different types of gases and the amount of those gases in the oil sample indicate any irregular behavior that is happening in the transformer. The gases are vacuumed from tightly-sealed containers that obtain small oil samples from transformers [9].

Water Content Test

The Water Content Test gives a reading for how much water, in parts per million, is in the liquid insulating material (commonly mineral oil) inside the transformer. This test is important due to the negative effect that water has on the dielectric material when is inside a transformer. A high water content in the insulating material will lower its dielectric breakdown voltage. This can cause critical failure in the transformer when the transformer's voltage overcomes the lower dielectric breakdown voltage [9].

Dielectric Strength Test

The oil in a transformer is meant to insulate electrical material from discharging or arcing due to the high voltage coming into the transformer. The dielectric strength of an insulating material is a measure of the material's ability to withstand electrical stress without failing. This test passes an electric current across a gap and records the voltage at which an arc occurs and when the dielectric strength breaks down [10]. This measurement is compared to the original dielectric strength and the condition of the transformer is predicted from that comparison.

Acidity Number

For oil analysis, testing the acidity of the oil can find problems with the insulation of the transformer. Acids inside the transformer can come from overheating the oil which causes decomposition and oxidation. Acids also come from moisture due to poor insulation. A high acidity level in the oil is an indication of the rate of deterioration of the oil. Sludge is an inevitable by-product of an acid situation so it is neglected [11].

Furaldehyde Test

In transformers, their solid insulation material is made of paper to help separate wires and prevent arcing. Furaldehyde are chemicals that are created when the cellulose paper inside the transformer degrades due to overheating [10]. These Furaldehyde chemicals that are found in the liquid insulation material of the transformer can give an indication of the status of the solid insulation and give a prediction of the health of the transformer.

Turns Ratio Test

A Turns Ratio Test is a common test for a transformer. The basic procedure is to apply a voltage to the input of the transformer and measure the resulting voltage on the output. The ratio of the two voltages is then compared to the ratio on the transformers nameplate. A deviation of more than 0.5% suggests that there is a turn to turn fault within the transformer [12]. This test is an effective tool for understanding the health of the transformers winding insulation.

Winding Resistance Test

The winding resistance test is an effective way to measure for opens or severely damaged windings. The tap changers of a transformer also affect the resistance measured and could be tested during this procedure [13]. The winding resistance of each phase is compared to each other; a deviation less than 1% is acceptable. Also, these resistances should be checked against past Winding Resistance test results, if applicable.

Excitation Current Test

An Excitation Current Test is a way to detect damage to the transformers core and/or its windings. The procedure is to apply a voltage to each HV winding and measure the resulting current. The applied voltage is normally no more than 10% of the rated voltage of that winding [6]. The results of the two phases on the outside should be within 15% of each other. The center phase has a lower magnetic reluctance, which results in a lower excitation current [6].

Frequency Response Analysis Test

The frequency response analysis test is used to determine movement of the transformers core, windings, or other mechanical faults. The basic idea of this test is to see how the transformer transmits a low voltage signal that changes in frequency [14]. By plotting the swept frequency vs. amplitude (dB) a fault is shown when the graph of one phase varies significantly from the other two.

Power Factor Test

The power factor test is an effective method of testing the strength of the transformers insulation before a fault occurs. The test is done by taking the ratio of the capacitive current and the resistive current, known as the Power Factor [15]. Ambient temperature and relative humidity are taken into account while performing this test. There are tables which are used to compensate for these external factors. A PF less than 1% is expected for a transformer in good condition [6].

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Requirements and Specification

Mechanical

APS has a Westinghouse Generation Step Up transformer currently in service. The transformer has shown signs suggesting it is near its end of the service. Mechanical problems have already occurred in the two failing pumps used to circulate cooling oil. This improper oil flow has started to cause unwanted hotspots throughout the transformer.

- 21200 gallons of oil
- Weight total: 753,000 lbs

Electrical

APS needs our team to assess the integrity of electrical components making up a transformer and determine their current state of repair. APS wants the assessment to give an estimated time for the remaining life of the transformer, as well as a suggested course of action.

- 3 phase 60 hertz
- Class F0A
- Impedance 17% at 305000 KVA
- 65° C average rise

Environmental
The environmental factors of the APS transformer are minimal for most of the transformer's life. There are some factors that we have to take in account for the life of the transformer such as oil temperature, winding temperature, noise, and vibration.

- Average 65 degrees Celsius in oil
- Average 70 degrees Celsius in copper windings
- 60 Hz hum and vibration

Documentation
APS need all documentation to be professional and submitted in a timely manner. Siemens, an outside testing company, is scheduled to investigate the transformer in April of 2013. Because of this, APS needs our report before that investigation occurs. APS wants the documentation to be technical, but still assessable to non-engineers. The health assessment report should contain a predictive analysis, reasons for failure, and a variety of tests which will help APS better understand the current condition of their transformer.

- Create a health assessment report by April 2013
- Cholla Unit 2 Generation Step Up Transformer serial number: 7002213
- APS' instruction book: EBM1057-12
- APS' wire diagram: EBM1057-04

Testing
In order to accurately determine the health of the transformer several tests will need to be performed. APS continues performing test that can be done while the unit is online such as oil dissolved gas analysis and acoustic testing. Our research is to include more online testing procedures and also tests that can be done during an upcoming outage.

- Dissolved Gas Analysis
- Water Content Test
- Dielectric Strength Test
- Acidity Number
- Furaldehyde Test
- Turns Ratio Test
- Winding Resistance Test
- Excitation Current Test
- Frequency Response Analysis
- Power Factor Test

General
The general aspects of the transformer being investigated are safety and reliability. Safety is a prime concern to APS as well as our team. Reliability is linked to the safety of transformers, because it governs the properties that decide if the transformer will fail under certain scenarios

- Electromagnetic radiation level as identified in ANSI std. C95.1
- Approximate life of the transformer is 40 years.

Design Section
Our final design for this project consists of a report that will be given to Arizona Public Service. This will include a three-part assessment of the transformer's condition. In this three part approach, we will analyze past data given to us by APS to establish any trends that may be present. Also, we will evaluate case studies of transformers' failures to understand what makes them fail.

Finally, our team will research a variety of test that could assist Arizona Public Service in characterizing the condition transformer.

Data Analysis

We were given results for tests done on Unit 2's generation step-up transformer from April 1990 to August 2007. These tests were Dissolved Gasses-in-oil Analysis Test, Dielectric Strength Test, Acid Test, Power Factor Test, and Water Content Test. The tests could reveal important information about the trends that the transformer is following. With our knowledge of the history of the transformer and the help of the data that has been given to us by APS, we can make an accurate assessment of the remaining life of the transformer.

Case Studies

In addition to historical data received from APS, we have been researching case studies of transformers that have failed. Learning from others mistakes and evaluating what could have been done better in the past is critical to developing a complete understanding of Unit 2's transformer. There is a plethora of cases available to examine. These studies could aid us in interpreting APS's data to show signs of when or why Unit 2's transformer could fail in the future by assisting our team in recognizing patterns in the data. An evaluation of these case studies will be included in our report to establish a knowledge base about transformers. By understating other transformer failures and their causes, we may apply our ongoing research to the transformer at the Cholla Power Plant.

Preliminary Analysis

Analyzing the data received from APS, we can infer some of the problems the transformer has gone through in the past. One of the test results that will be looked at will be the results from the water content test. The water content test detects the moisture content in parts per million (ppm) of the liquid insulation [9].

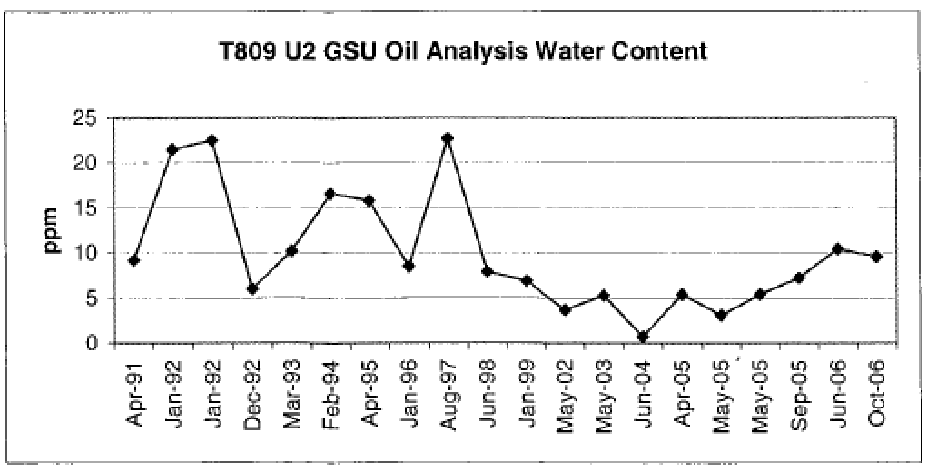


Figure 2

Relatively early on in the transformer's life, there were spikes in the water content within the transformer. This could have happened due to poor insulation outside of the transformer which let moisture inside the transformer as well as other factors within the transformer**.** In figure 2, shows steep spikes as well as sharp drops in water content inside the transformer. These step drops could be from result of APS fixing the transformer from year to year due to the sudden increases in water content. As the timeline continues to October 2006, the water content levels in the transformer start to stabilize at 10 ppm but those early fluctuations could have caused damage to other parts of the transformer.

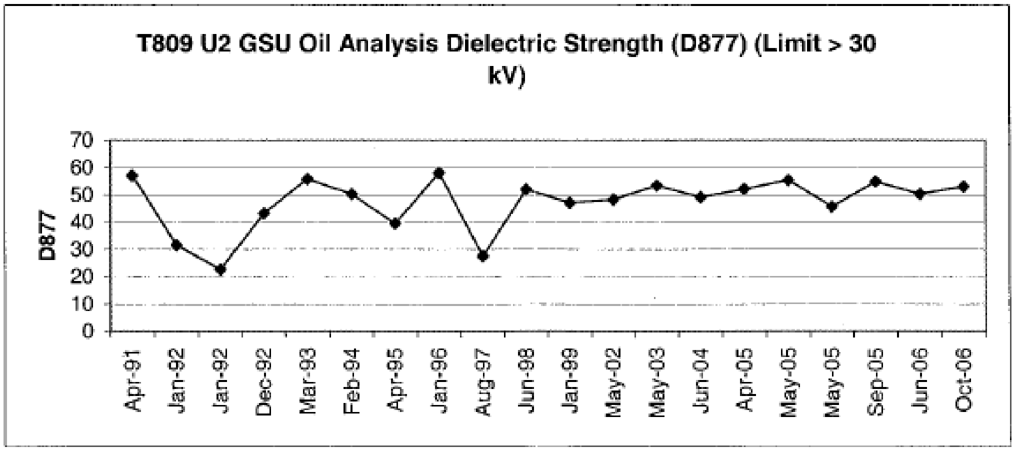


Figure 3

Potential residual effects from the steep variations in the water content could have caused drops in the strength of the dielectric properties of the insulating oil. Figure 3 shows results from a dielectric breakdown test which measured the voltage at which the dielectric strength of the oil breaks down [9]. The graph in figure 3 shows a sudden drop of the dielectric strength of the material to its lowest value during January 1992, the same date that the water content levels were at their highest. As the water content stabilizes, the dielectric strength of the oil also stabilizes. These two graphs show an inverse relation between the water content and the dielectric strength of the liquid insulation inside the transformer. As the water content level rises, the dielectric material falls at almost the same rate as the water content level.

Testing

Testing is used to determine the current state of a transformer. We will continue our research into the types of tests that could be used to establish a transformer's health. Understanding how these tests work and what type of problems they identify within a transformer is important to know, because it will allow us to give a general assessment of why the transformer is not working properly. Currently, we have studied fourteen tests. Of these (more tests could be also looked at), we hope to give Arizona Public Service additional knowledge they could use to potently diagnose a problem with the transformer.

Condition Assessment/Course of Action

By utilizing data analysis, case studies, and testing, we believe that our team can give an accurate estimate of the transformer's overall condition. **We stipulate that APS is to take these results along with our conclusion about Unit 2's transformer as only academic recommendations.**

Constraints

Cost

It is required by our team to stay within the budget of $2000 given to us by APS. The majority of our expenditures will be used for transportation and meeting expenses. Northern Arizona University allows our team to perform research using their resources at no charge to APS. We feel that the budget given to us is sufficient to complete the project.

Sustainability
The transformer must remain in service until the scheduled visual inspection during March 2013. This means that any test that our team would like to perform must be allowable while the unit is online. We will be providing APS a well-established course of action regarding the future of this transformer. These suggested actions include preventative maintenance, testing strategies, and the life expectancy of this transformer.

Ethical
Determining the life expectancy of the transformer will require a strict following of the IEEE code of ethics. All data accumulated during the project will be carefully analyzed and gathered to help us accurately predict the remaining life. All recommendations will be backed by research and scientific data. Any consequences which may occur due to our recommendation will be thoroughly evaluated.

Health/Safety
As professional engineers and aspiring engineers it is our duty to maintain strict safety rules that keep all parties involved safe from harm or injury. All testing will be precisely monitored and only performed by trained professionals. If at any time our team finds data or a procedure that may lead to the harm of personnel or equipment, APS will be notified immediately.

Testing – Prior to Outage

For the analysis of the dissolved gasses that are in the transformer oil we used four different methods that we have found to be useful during our research. The four methods of dissolved gas analysis are Key Gases, Dornenburg's Ratio, Rogers Ratio, and Duval's Triangle. All of these tools, expect for Duval's Triangle, are thoroughly discussed in the IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers. The downside to these techniques is that don't tell you about whether a fault is active of if it only occurred in the past. Due to inaccuracies, none of these methods should be used alone for interpretation of dissolved gas. However, using the results from all four techniques during analysis can be useful in predicting what type of faults may have occurred inside of a transformer.

We have been and will continue to analyze the dozens of gas samples which has been provided to us by APS. Using each of these four techniques on all of our data would be a time consuming and daunting task. To help us with this issue we have programmed these analysis tools into excel. This enables us to paste the gas data into a spreadsheet and the results from each technique are then automatically generated. This is a useful tool for us to analyze our current data. In addition, APS will also be able to use this for studying future gas samples.

Key Gases
The Key Gases technique evaluates the relative proportions of Carbon Monoxide, Hydrogen, Methane, Ethane, Ethylene, and Acetylene. This method is helpful in interpreting the general type of fault which may be located in the transformer. The premise is that certain gases will only form under specific operating conditions of the transformer. Tables 1 through 4 are used for the key gases analysis.

Table 1
Overheated Oil

1. Thermal – Oil: Decomposition products include ethylene and methane, together with smaller quantities of hydrogen and ethane. Traces of acetylene may be formed if the fault is severe or involves electrical contacts.

Principal Gas – Ethylene

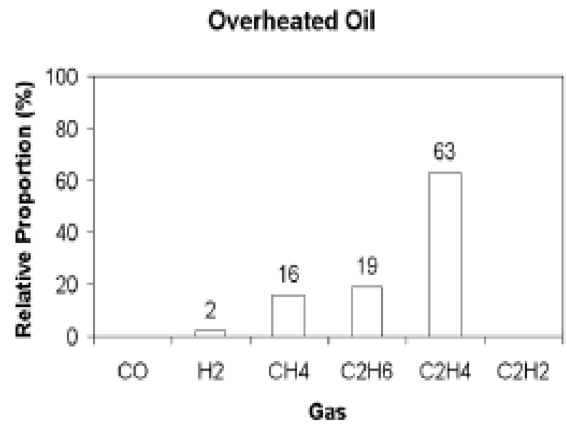


Table 2
Overheated Cellulose

2. Thermal – Cellulose: Large quantities of carbon dioxide and carbon monoxide are evolved from overheated cellulose. Hydrocarbon gases, such as methane and ethylene, will be formed if the fault involves an oil-impregnated structure.

Principal Gas – Carbon Monoxide

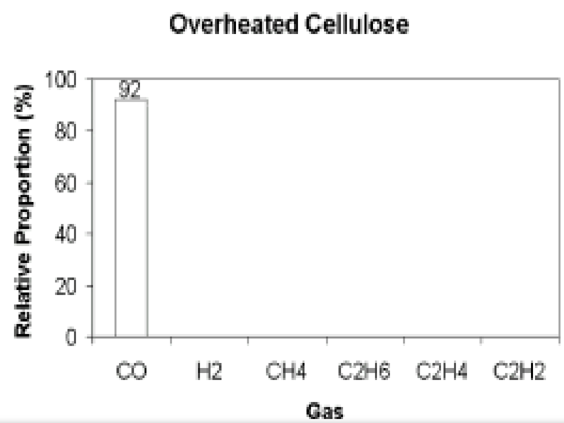


Table 3
Partial Discharge in Oil

3. Electrical – Partial discharge: Low-energy electrical discharges produce hydrogen and methane, with small quantities of ethane and ethylene. Comparable amounts of carbon monoxide and carbon dioxide may result from discharges in cellulose.

Principal Gas – Hydrogen

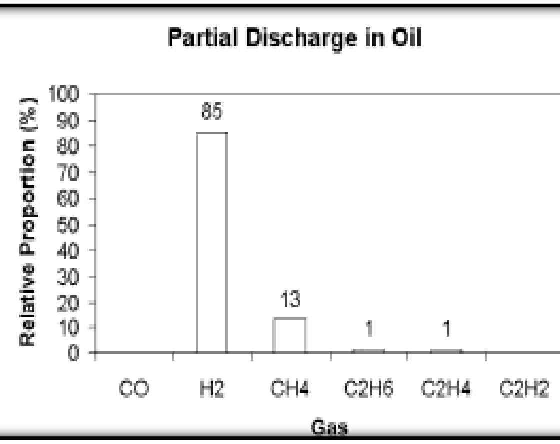
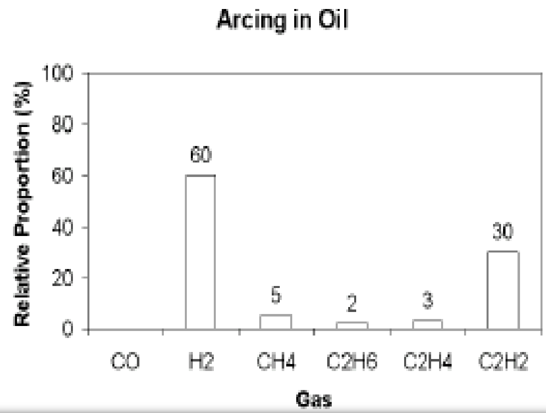


Table 4
Arching in Oil

4. Electrical – Arcing: Large amounts of hydrogen and acetylene are produced, with minor quantities of methane and ethylene. Carbon dioxide and carbon monoxide may also be formed if the fault involves cellulose. Oil may be carbonized.

Principal Gas – Acetylene



Dornenburg's Ratio

Two of the tools we used for dissolved gas analysis compare ratios of the key gases described earlier. Dornenburg Ratio is not often used because it requires high concentration of gases to be present in order for the analysis to be considered valid. This being said, if the gas concentrations are great enough then Dornenburg Ratio analysis can be an effective tool.

Table 5
Dornenburg Ratios for Key Gases

Suggested fault diagnosis	Ratio 1 (R1) CH_4/H_2		Ratio 2 (R2) C_2H_2/C_2H_4		Ratio 3 (R3) C_2H_2/CH_4		Ratio 4 (R4) C_2H_6/C_2H_2	
	Oil	Gas space	Oil	Gas space	Oil	Gas space	Oil	Gas space
1. Thermal decomposition	>1.0	>0.1	<0.75	<1.0	<0.3	<0.1	>0.4	>0.2
2. Partial discharge (low-intensity PD)	<0.1	<0.01	Not significant		<0.3	<0.1	>0.4	>0.2
3. Arcing (high-intensity PD)	>0.1 to <1.0	>0.01 to <0.1	>0.75	>1.0	>0.3	>0.1	<0.4	<0.2

Rogers Ratio

Roger's ratio is similar to Dornenburg's ratio because it not only looks at the ratio of key gases found but also requires a minimum concentration for the gas sample to provide credible results. However, this tool has been used for thousands of transformers and has provided credible results.

Table 7
Roger's Ratios for Key Gases

Case	R2 C_2H_2/C_2H_4	R1 CH_4/H_2	R5 C_2H_4/C_2H_6	Suggested fault diagnosis
0	<0.1	>0.1 to <1.0	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Low-energy density arcing—PD*
2	0.1 to 3.0	0.1 to 1.0	>3.0	Arcing—High-energy discharge
3	<0.1	>0.1 to <1.0	1.0 to 3.0	Low temperature thermal
4	<0.1	>1.0	1.0 to 3.0	Thermal < 700 °C
5	<0.1	>1.0	>3.0	Thermal > 700 °C

*There will be a tendency for the ratios R2 and R5 to increase to a ratio above 3 as the discharge develops in intensity

Duval's Triangle

The Duval Triangle dissolved gas analysis tool has also been proven to be helpful in interpreting possible faults within a transformer. It uses the proportions of the three key gases Acetylene, Ethylene, and Methane to determine what type of fault may have occurred in the transformer. Duval's Triangle should be used with caution because it will always say that there is some kind of fault in the transformer even if it is operating normally. In most cases, this tool is used after a fault has been determined by some other method to verify the results. The benefit of this tool is that it will not only determine the type of fault but also the severity.

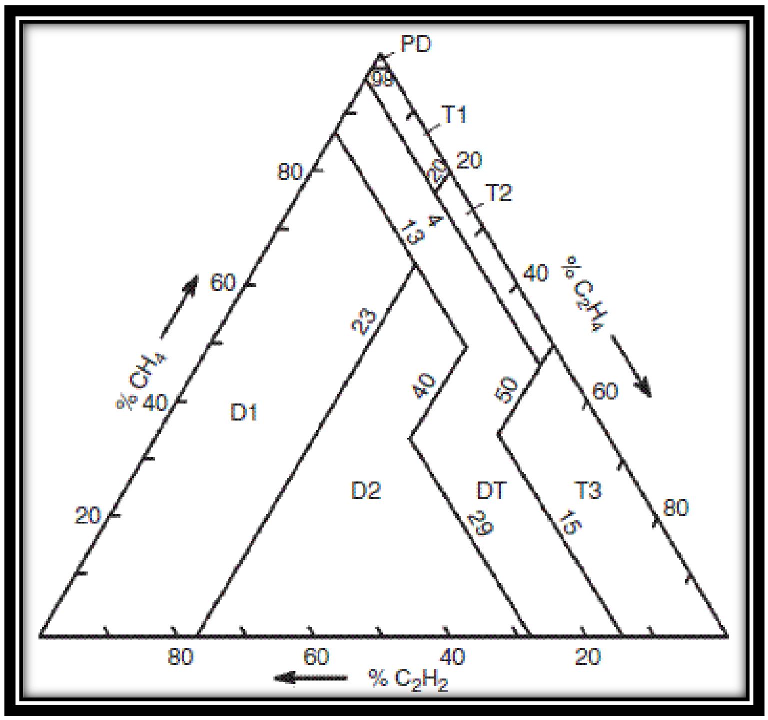


Figure 4
Duval Triangle

Symbols	Faults	Examples
PD	Partial discharges	Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper
D1	Discharges of low energy	Partial discharges of the sparking type, inducing pinholes, carbonized punctures in paper Low energy arcing inducing carbonized perforation or surface tracking of paper or the formation of carbon particles in oil
D2	Discharges of high energy	Discharges in paper or oil, with power follow through, resulting in extensive damage to paper or large formation of carbon particles in oil, metal fusion, tripping of the equipment and gas alarms
DT	Thermal and electrical faults	Mixture of thermal and electrical faults
T1	Thermal fault, T<300°C	Evidenced by paper turning brownish (>200°C) or carbonized (>300°C)
T2	Thermal fault, 300<T<700°C	Carbonization of paper, formation of carbon particles in oil
T3	Thermal fault, T>700°C	Extensive formation of carbon particles in oil, metal coloration (800°C) or metal fusion (>1000°C)

Below is a DGA sample taken on October 10 24th, 2012. During this time period two of the four oil pumps were inactive causing improper circulation for cooling the mineral oil. All four DGA methods indicate overheating of the oil which in likely due to the inactive pumps.

Ethylene	218.9954
Hydrogen	52.1718
Methane	107.0636
Ethane	137.2955
Acetylene	0.2361
CO	31.5989
TDCG	547.3613

Doernenburg ratio: Thermal Fault

Rogers ratio: Thermal Fault<700°C

Duval Triangle: Thermal Fault>700°C

Key Gas: Thermal - Oil

Water Content Analysis

Analyzing the data received from APS, we can infer some of the problems the transformer has gone through in the past. One of the test results that will be looked at will be the results from the water content test. The water content test detects the moisture content in parts per million (ppm) of the liquid insulation.

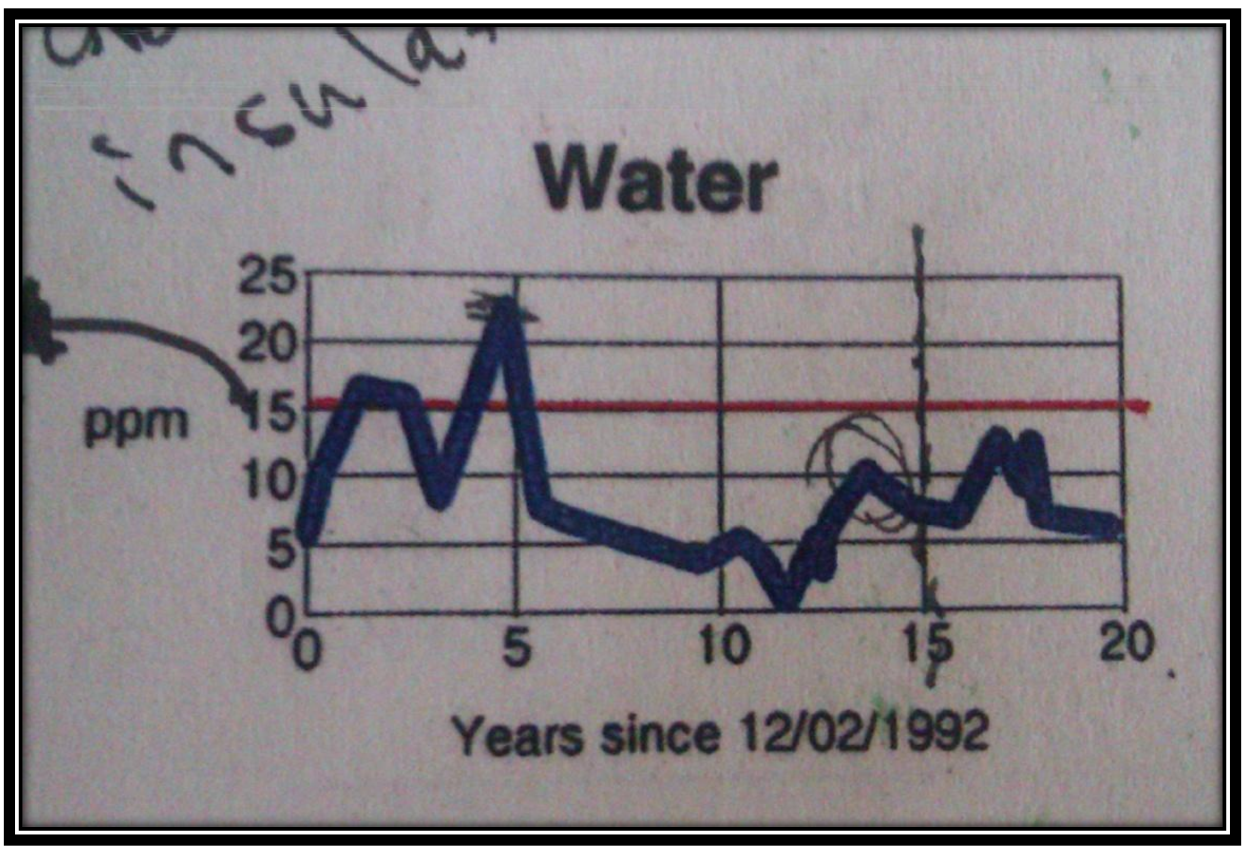


Figure 5
Dissolved Gas Analysis Data Received from APS

Relatively early on in the transformer's life, there were spikes in the water content within the transformer. In Figure 5, shows steep spikes as well as sharp drops in water content inside the transformer. These step drops could be from result of APS fixing the transformer from year to year due to the sudden increases in water content. As the timeline continues to October 2006, the water content levels in the transformer start to stabilize at 10 ppm but those early fluctuations could have caused damage to other parts of the transformer. The water content in the oil goes over 15 ppm in the water content test three times and has past 20 ppm once sense 1991(close to half the transformer's total life). The Bureau of Reclamation has recommended that transformers over 230kV should never exceed 12 ppm so this water level in the oil of the transformer could be a sign of problems in the transformer. These levels of moisture in a transformer could have happened due to small oil leaks which will allow moisture in the transformer as well as the degradation of the solid insulation.

These signs of high water content could have a negative effect on the solid insulating material within the transformer. The graph in Figure 6 gives us a relationship between moisture in oil and the moisture in the paper insulation material; as the temperature in the oil decreases and moisture in the insulating oil increase then the moisture in the paper insulation will increase. The green line in the graph shows the characteristics of the transformer we are currently analyzing at one of its most critical water content points. It should be noted that moisture in oil in not necessarily an indicator of moisture in paper. The moisture content can change quickly during warm up and cool down of a transformer.

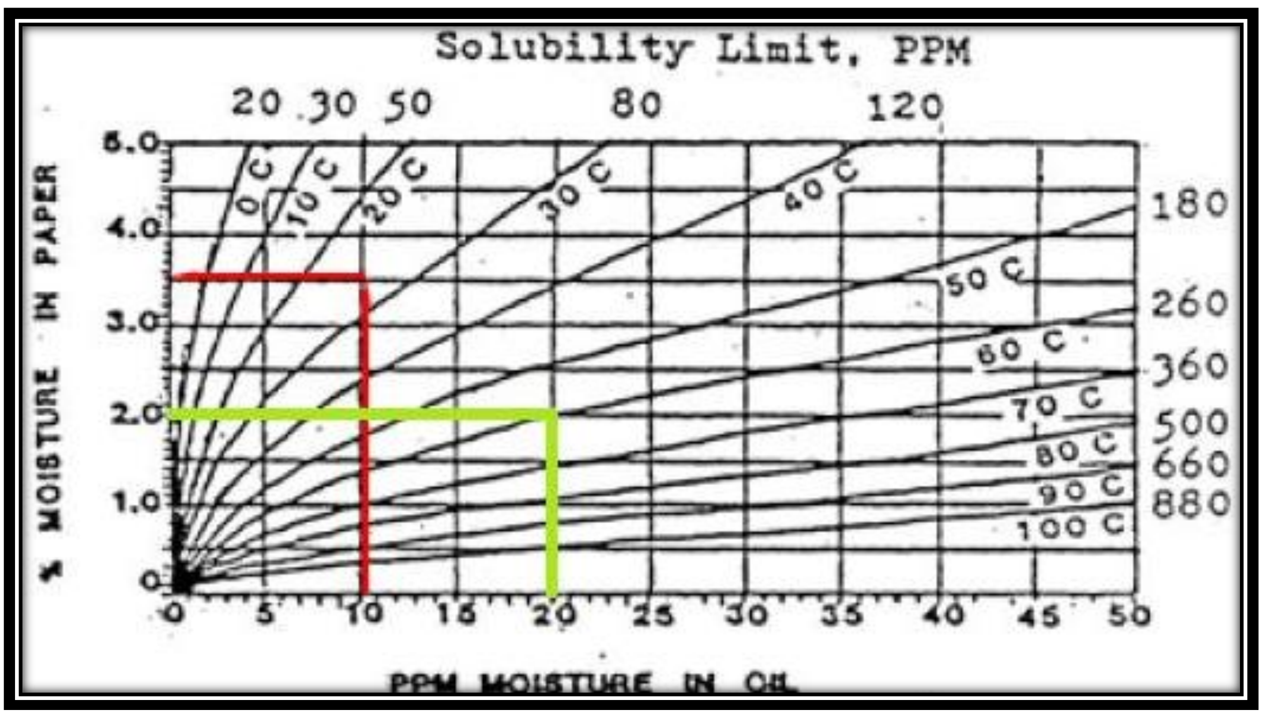


Figure 6
Moisture Equilibrium Curves

The IEEE Guide for Oil Filled Power Transformers gives us a guide on how to interpret the percent moisture in the paper we gathered from the graph above. Our transformer has a 2% moisture in paper which falls between the "dry paper" and "wet paper" condition given in Table 8.

Table 8
Guidelines for interpretation of % moisture by dry weight of paper [18]

% Moisture by dry weight in paper	Condition
0-2	Dry paper
2-4	Wet paper
>4.5	Excessively wet paper

Dissolved Gas Analysis - Oxygen

It is critical for life extension to keep transformers as dry and as free of oxygen as possible. Cellulose degrades much faster than oil because it contains oxygen within its molecular structure. The degradation process generates water, carbon dioxide and furfurals, and is accelerated by external sources of oxygen, high temperature and high levels of oil acidity. The dissolved gas analysis data we received from APS in Figure 7 shows that there was a spike of oxygen close to two years ago. This spike of oxygen does not help the life of the transformer but stands as an incident that would reduce the life of the transformer. The rise in oxygen could signal more water that was added to the paper insulation and signal further reduction of the insulating properties of the paper.

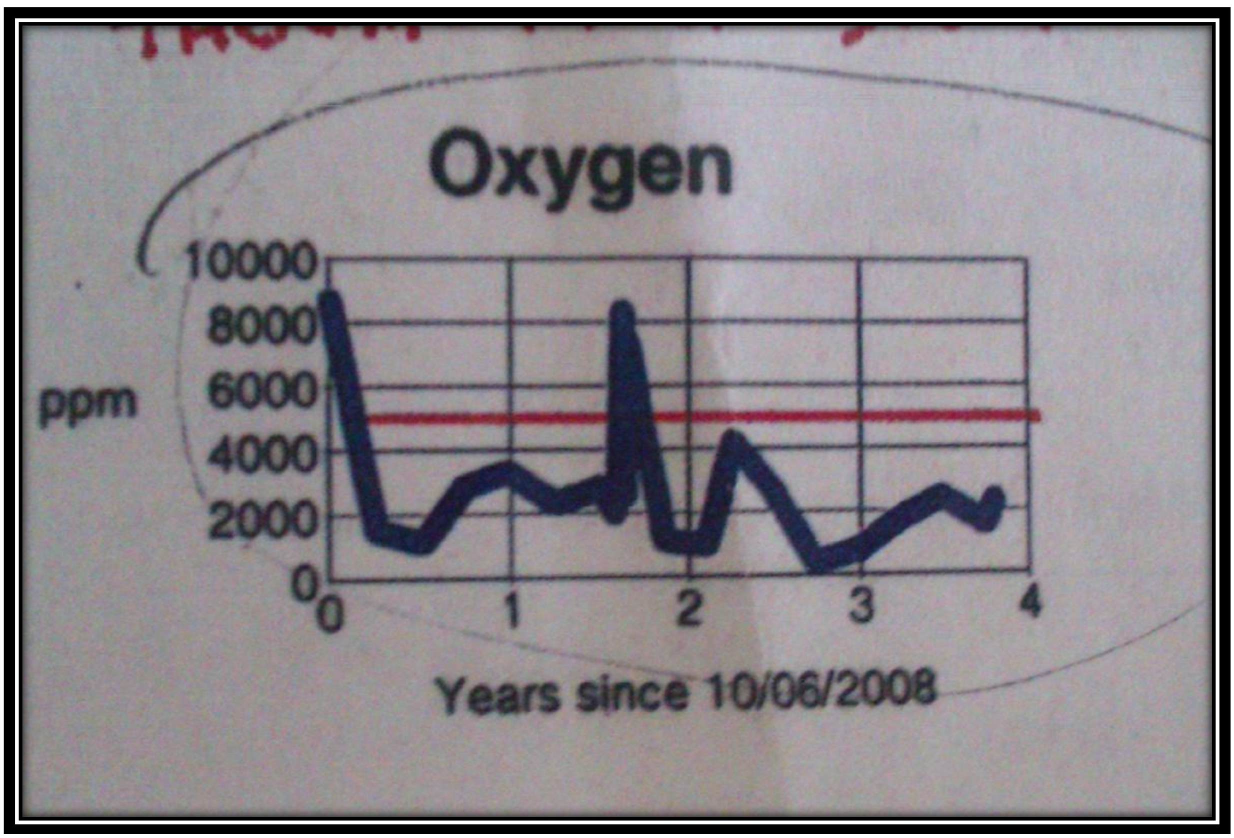


Figure 7
Dissolved Gas Analysis Data Received from APS

Hot Spot Analysis

Recently, thermal images were taken of the transformer we are assessing which indicated that there were areas of extreme heat compared to the rest of the transformer, in Figure 8. Reasons why there was a high water content in the transformer could be from degradation in the solid insulation material between the coils of the transformer. Natural wear on the solid insulation could pose health problem with the transformer because this drops the insulating material's strength. Drops in the solid insulating material strength can cause arching between the coils inside of the transformer and cause local hot spots in certain areas of the transformer. Common among many of the transformer failures is a short turn. The shorted turn develops as a result of breakdown of the solid insulation which causes winding temperature to shoot up. The transformer shows signs of a short turn which would suggest that it's at the end of its life.

Figure 8
Thermal Picture Comparison of the Unit 2 Transformer

Preliminary Conclusion

Further tests need to be done to get condition assessment for the transformer. Figure 9 describes the characteristics of a transformer when the insulation age drops after certain high load stresses. It can be seen that past failures and stress affect the state of the transformer. When additional tests are completed during and after the outage we can make our condition assessment.

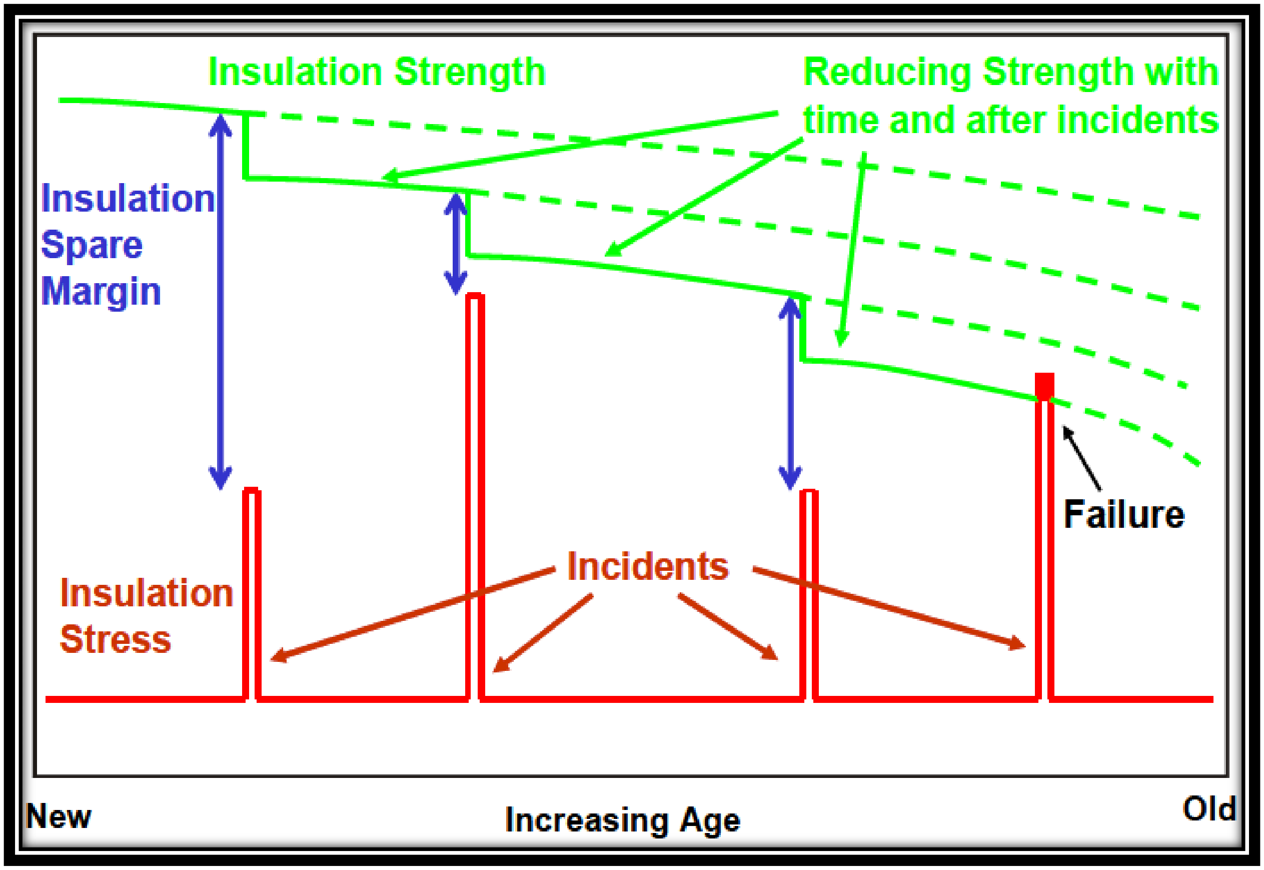


Figure 9
A Conceptual Failure Model

Testing – During Outage

The following is the analysis of tests performed on April 1st 2013 for the U2 GSU. These tests were performed when the transformer was offline, and after the visual inspection. This occurred just prior to the transformer going back online.

Overall Power Factor

The purpose of the Overall Power Factor test is to check for moisture and contamination in the oil and embedded in the cellulose. A power factor greater than 1% for this test indicates that there may be unwanted moisture or contamination in the transformer. All of these tests' points were well below the 1% limit. This is shown in the highlighted section of Table 9.

Table 9
Power Factor Data

Meas.	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap(pF)	IR_{auto}	IR_{man}
CH + CHL	10.005	96.179	3.559		1.00	25511.9		
CH	10.002	33.997	1.108	0.33	1.00	9017.6	G	
CHL(UST)	10.003	62.130	2.472	0.40	1.00	16480.3	G	
CHL		62.182	2.451	0.39	1.00	16494.300	G	
CL + CHL	10.007	180.80	8.175		1.00	47959.0		
CL	10.003	118.63	5.656	0.48	1.00	31466.8	D	
CHL(UST)	10.003	62.122	2.471	0.40	1.00	16478.2	G	
CHL		62.170	2.519	0.41	1.00	16492.200	G	
CH'		24.108	0.793	0.33	1.00	6394.610		

Bushing C1 Power Factor

The purpose of the Bushing C1 Power Factor test is to check for contamination in the main body of the transformer. A power factor greater than 0.5% indicates that a bushing has deteriorated and should be investigated. None of the test points were greater than 0.5% as shown in Table 10.

Table 10
Bushing C1 Power Factor Data

ID	Serial #	NP %PF	NP Cap	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap (pF)	IR_{auto}	IR_{man}
H1	5C07015303	0.27	455	10.005	1.685	0.0530	0.29	0.95	447.07	G	
H2	5C07015302	0.26	452	10.006	1.697	0.0530	0.30	0.96	450.08	G	
H3	5C07015301	0.32	461	10.005	1.695	0.0580	0.33	0.96	449.54	G	
H01	5C06932001	0.26	426	10.005	1.605	0.0500	0.30	0.96	425.79	G	
H02	5C06932003	0.26	425	10.005	1.603	0.0510	0.31	0.96	425.10	G	
H03	5C06932002	0.26	426	10.015	1.604	0.0500	0.30	0.96	425.41	G	

Bushing C2 Power Factor

The purpose of the Bushing C2 Power Factor test is to check for contamination in the oil and the winding tap area. A power factor greater than 1% indicates that a bushing has deteriorated and should be investigated. Table 11 demonstrates that none of the test points were greater than 1%.

Table 11
Bushing C2 Power Factor Data

ID	Serial #	NP %PF	NP Cap	Test kV	mA	Watts	%PF corr	Corr Fctr	Cap (pF)	IR_{auto}	IR_{man}
H1	5C07015303	0.26	7267	2.000	27.284	0.7160	0.26	1.00	7237.4	G	
H2	5C07015302	0.28	7270	2.000	27.242	0.7890	0.29	1.00	7226.1	G	
H3	5C07015301	0.29	7064	2.000	26.500	0.7200	0.27	1.00	7029.2	G	
H01	5C06932001	0.16	369	0.5000	1.393	0.0210	0.15	1.00	369.37	G	
H02	5C06932003	0.16	384	0.5000	1.453	0.0530	0.36	1.00	385.44	G	
H03	5C06932002	0.19	378	0.5000	1.429	0.0520	0.36	1.00	379.14	G	

Turns Ratio Test

The purpose of the Turns Ratio test is to check for shorts in the transformer windings. The U2 GSU is used in the tap changer position 4. With the tap changer in this position, the minimum turn ratio value is 13.741 and the maximum limit is 13.879. None of the winding ratios measured outside of the acceptable range. This data was captured in Table 12.

Table 12
Turns Ratio Data

Mfr				Serial #		HV Winding			LV Winding		
Raytech				261-110		L-L			L-L		
Connections				H1 - H01		H2 - H02			H3 - H03		
				X1 - X2		X2 - X3			X3 - X1		
Tap	NP Volt	Tap	NP Volt	Cal	Ratio 1	Ratio 2	Ratio 3	Min. Lim	Max. Lim	IR_{auto}	IR_{man}
1	551250	NA	21400	14.872				14.798	14.947		
2	538125	NA	21400	14.518				14.445	14.591		
3	525000	NA	21400	14.164				14.093	14.235		
4	511875	NA	21400	13.810	13.850	13.842	13.852	13.741	13.879	G	
5	498750	NA	21400	13.456				13.388	13.523		

Degree of Polymerization

During the visual inspection of the transformer, several cellulose insulation samples were taken from varies areas of the transformer. These samples were sent to Doble Engineering for Degree of Polymerization (DP) testing. A DP test will indicate the remaining life of the paper insulation of the transformer.

Cellulosic insulation with DP values of 200 or below is considered near or at the end of the reliable life and at this point the paper insulation has become mechanically compromised. Midlife is approximated at a DP of 400 and new paper typically has a DP of about 1000 to 1300. Aging of the cellulose insulation within a transformer is very rarely uniform and, therefore, the location where the sample is taken is important. Out of the 6 samples tested the worst case is that the paper insulation has 86% of its life remaining. This is very good for a transformer that has been in service for 38 years. This information is shown in Table 13.

Table 13
Degree of Polymerization Data

Sample #	Report #	Sample Date	DP	Estimated Remaining Life to DP 200 (%)
1	126644	*04/03/2013*	849	95
2	126644	*04/03/2013*	903	97
3	126644	*04/03/2013*	927	98
4	126644	*04/03/2013*	759	90
5	126644	*04/03/2013*	690	86
6	126644	*04/03/2013*	849	95

Testing – After Outage

Dissolved Gas Analysis (DGA)

Below is the DGA from the most recent oil sample from the transformer. This sample was taken on April 22nd, 2013, approximately 3 weeks after the transformer was put back into service. Three of the four DGA methods show that there is "No Fault" with the transformer. Duval's triangle does not have the option to suggest that there is no fault and should only be used when another DGA method indicates there is a fault.

	ppm
Ethylene	23.1981
Hydrogen	9.1989
Methane	20.9397
Ethane	42.8143
Acetylene	0
CO	43.7089
TDCG	139.8599

Dornenburg's ratio:	No Fault
Rogers ratio:	No Fault
Duval Triangle:	Thermal Fault>700°C
Key Gas:	No Fault

Closing Remarks

A separate *Condition Assessment* document will accompany this final report. This information will also be provided on our team's website at:
http://www.cefns.nau.edu/interdisciplinary/d4p/EGR486/EE/13-Projects/Transformer/index.html

Condition Assessment

None of the tests performed indicate that the transformer is in poor condition. From the analysis of data from electrical tests and dissolved gas analysis we are confident that the transformer can continue to operate normally.

We recommend monthly sampling of the mineral oil for Dissolved Gas Analysis and oil fluid tests. Any steady increase of gases or abnormalities in the fluid test during the monthly samples should be investigated immediately.

Project Critique

Our team successfully completed a condition assessment of the U2 Generation Step Up transformer located at the Cholla Power Plant in Joseph City, Arizona. Our overall goal was to provide our client, Arizona Public Service, with a condition assessment report. This report contains information on the research we conducted, analysis of data which we received, and our conclusion of the current condition of the transformer.

Research

Our research consisted of why transformers fail and how to conduct tests which will help us with assessing the condition of the transformer. We found that the main reasons why transformers fail were insulation failure, design, unknown reasons, loose connections, and overloading. Since insulation failure was the top reason for transformer failure, we concluded that testing of the paper insulation was crucial for us to be confident with the condition assessment which we provided. There were several tests which could be performed on the transformer in order to test the strength of the insulation, such as Insulation Power Factor, Turns Ratio, and Degree of Polymerization.

Data Analysis
The data analysis was performed on both data from the history of the transformer and also data that was gathered when the transformer was taken offline in the spring of 2013. While looking at the history of the transformer, in the form of data gathered over its lifetime, we looked for possible indication that the transformers health had been compromised. There were minor concerns found with the moisture in oil test, thermal imaging, and dissolved gas analysis. However, none of this data was strong enough evidence that the transformer was near the end of life.

The tests performed on the transformer when it was taken offline gave us the strongest evidence of the current condition of the transformer. The transformer was completely drained of its oil so that the aging cooling pumps could be replaced. This allowed us to perform a visual inspection of the transformer. While in the transformer, several insulation paper samples were taken so that a Degree of Polymerization test could be performed. After the oil was placed back into the transformer several electrical tests were performed to help analyze the condition of the transformer.

Conclusion
Based on the research that was performed and the data we evaluated we were able to provide Arizona Public Service with a confident assessment of the Unit 2 GSU at Cholla. Also, we provided APS with a recommendation of preventative maintenance that should be performed on the transformer. With this information APS can confidently continue to provide their customers with safe and reliable power.

Budget

Our initial verbal agreement for the project this project was to stay under $2,000; this was achieved. The largest contributor to expenses was the gas for traveling to the power plant a total of four times. The next was food during these travel times as well as during meetings. The last contributor was a transformer maintenance book that was vital to properly analyzing the condition of our transformer. The money spent for this total project was approximately $781.

Reimbursed Expenses:
Travel $508.00
Books $103.00
Food $ 170.00
Total: 781.00

Schedule

Summary of Events
Currently the project is on schedule and a completed condition assessment will be given to Arizona Public Service before May, 10th 2013. During the winter break an excel spread sheet was programed using three methods of dissolved gas analysis to formulate a possible cause to the shortened life expectancy. This was a very important milestone in our project as it gave us our first clue into the

reason for the shorten life expectancy. We met again to further discuss what was needed for our report with APS and we also obtained more data to use in our condition assessment of the transformer. Our website will be coming to completion shortly, and it should be finished by May 9th, 2013. During the spring semester we obtained the rest of the data needed for our assessment of the transformer. A significant milestone was on March 19th when the transformer went offline for maintenance and an inspection. During this time period the remaining data we needed for a proper assessment was obtained. From this important data, our knowledge was used to create the condition assessment. We finished our assessment and have included its results in this report. The Last milestone for the project will be providing APS with this report and a separate condition assessment for the transformer.

Time Spent on Project

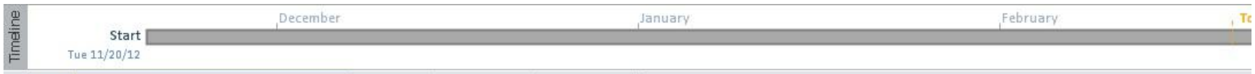
The first step in our project was problem identification which included our initial meeting with the client as well as phone meetings to better understand the client's requirements. The time spent on this section of the report was 60 man hours. After we knew what the scope of the project was we began 350 man hours of research including why transformers fail, transformer designs, and proper testing protocol. The next section was brainstorming in which we analyzed the current data for a total of 140 man hours. This then allowed us to begin compiling our assessment analysis as well as our overall data into our final report for 100 man hours. Lastly this data was presented our project during the fall and spring semesters for a total of 60 man hours.

Table 14
Hours Worked by Team

Problem Identification:	60 hours
Research:	350 hours
Brainstorm:	140 hours
Create:	100 hours
Present:	60 hours
Total:	**710 hours**

Scheduling

The scheduling throughout the project stayed completely on track and no adjustments were needed. This is a rare occurrence and was due to careful planning, and great communication within the team. This ensured deadlines that were set were met before they were due. The key to meeting all deadlines was great communication and reminding each other when things need to be done. For future projects we will make sure to plan in a very similar manner to allow plenty of time to complete an assigned task. There will also be an increase in communication between group members to increase the productivity and ideas in the group to help produce an even better product.



	Task Name	Duration	Start	Finish
1	**Andy**	**120 days**	**Tue 11/20/12**	**Sun 5/5/13**
2	Web site Integration	6 days	Mon 2/11/13	Sat 2/16/13
3	Review of previous gas data	10 days	Tue 11/20/12	Sat 12/1/12
4	Thermal issue from analysis	0 days	Sat 1/5/13	Sat 1/5/13
5	Gas analysis	37 days	Sun 12/2/12	Sun 1/20/13
6	Review extra data from APS	13 days	Tue 2/12/13	Thu 2/28/13
7	Life assessment	47 days	Fri 3/1/13	Sun 5/5/13
8	**Kenny**	**74 days**	**Tue 1/22/13**	**Sun 5/5/13**
9	Gas analysis research	28 days	Tue 1/22/13	Thu 2/28/13
10	Web site Detailed Design info	6 days	Mon 2/11/13	Sat 2/16/13
11	UGrads Poster	11 days	Tue 2/19/13	Tue 3/5/13
12	Life assessment	47 days	Fri 3/1/13	Sun 5/5/13
13	Final report	16 days	Mon 4/15/13	Sun 5/5/13
14	**Kyle**	**119 days**	**Tue 11/20/12**	**Sun 5/5/13**
15	Web site problem identification	6 days	Mon 2/11/13	Sat 2/16/13
16	Review of previous gas data	10 days	Tue 11/20/12	Sat 12/1/12
17	Gas analysis	37 days	Sun 12/2/12	Sun 1/20/13
18	Review extra data from APS	13 days	Tue 2/12/13	Thu 2/28/13
19	Life assessment	47 days	Fri 3/1/13	Sun 5/5/13
20	**Rich**	**60 days**	**Mon 2/11/13**	**Sun 5/5/13**
21	Web site Proposal	6 days	Mon 2/11/13	Sat 2/16/13
22	Ugrads Poster	11 days	Tue 2/19/13	Tue 3/5/13
23	Life assessment	47 days	Fri 3/1/13	Sun 5/5/13
24	Final report	16 days	Mon 4/15/13	Sun 5/5/13
25	**Scott**	**59 days**	**Tue 2/12/13**	**Sun 5/5/13**
26	Web site HTML	6 days	Tue 2/12/13	Tue 2/19/13
27	Excel spreadsheet improvements	20 days	Tue 2/12/13	Sun 3/10/13
28	Ugrads Poster	11 days	Tue 2/19/13	Tue 3/5/13
29	Life assessment	47 days	Fri 3/1/13	Sun 5/5/13
30	Final report	16 days	Mon 4/15/13	Sun 5/5/13
31	Transformer goes offline	8 days	Fri 3/15/13	Tue 3/26/13
32	Met with client for end product	0 days	Tue 2/12/13	Tue 2/12/13
33	Website Completion	0 days	Tue 2/19/13	Tue 2/19/13
34	Ugrads Poster Due	0 days	Tue 3/5/13	Tue 3/5/13

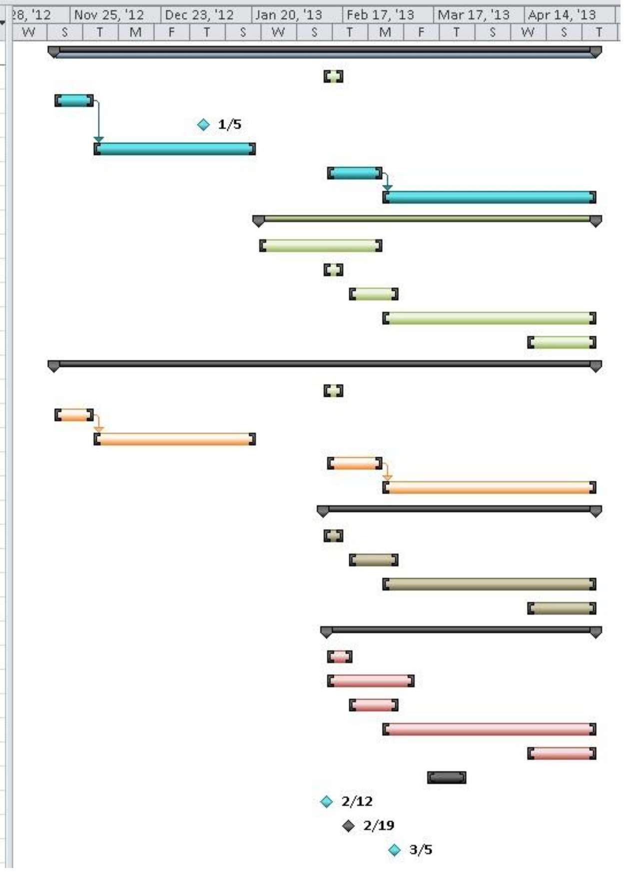
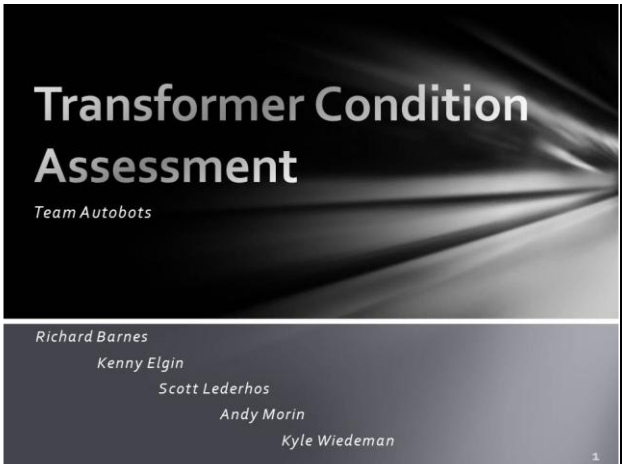
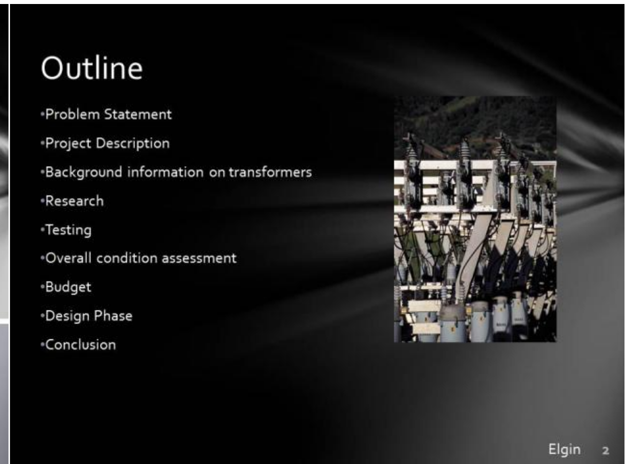
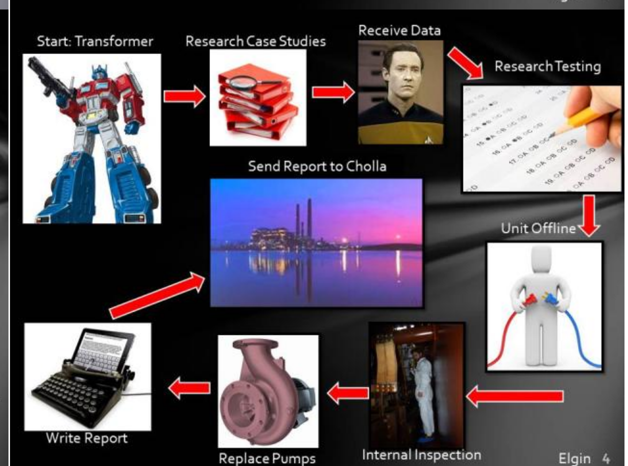


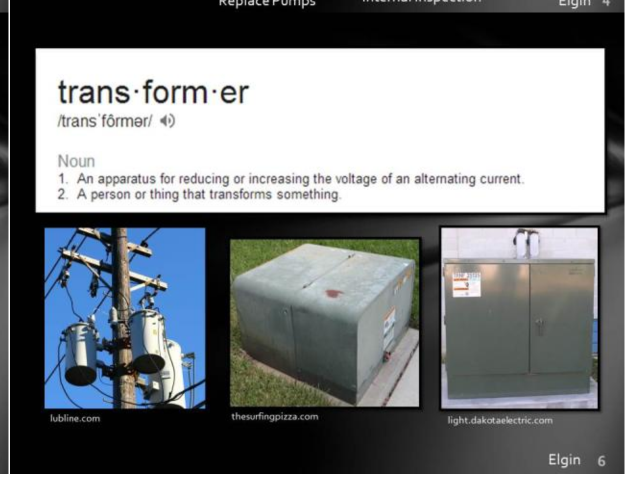
Figure 10
Final Schedule

Power Point Presentation









APS Unit 2 Generator Step Up Transformer

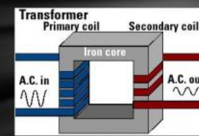
- Height: 18 ft
- Rating: 305 MVA
- Weight: 753,000 lbs.
- Oil Volume: 21,200 gallons
- Voltage: 21.4kV / 525kV
- Made: Jan. 1975
- Type: Shell Form

Elgin 7

Cholla's Unit 2 GSU

Electrically

- Number of turns determines output voltage
- Wye-Delta configuration
- Steps voltage up from generator to distribution lines. 21.4kv/525kv



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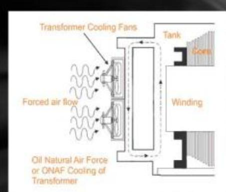
Elgin 8

Cholla's Unit 2 GSU continued…

Mechanically

- Dissipation of heat necessary
- Forced air and oil cooled
- 4 pumps and 16 fans



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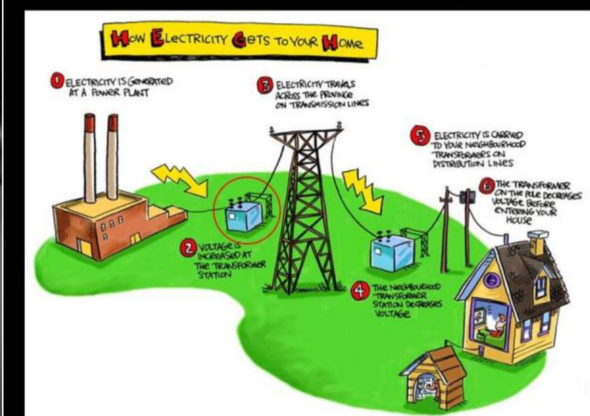
Elgin 9



bpbtecscience.wikispaces.com

Elgin 10

Research

- At the beginning of this project, our group had little to no experience determining the condition of a transformer.
  - Transformer designs
  - Reasons for transformers failure
  - Testing strategies and procedures

Barnes 11

Design: Power Transformers are Unique; Like a snowflake

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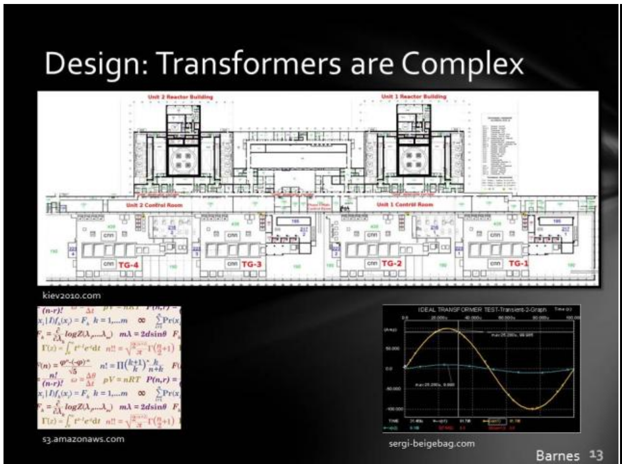
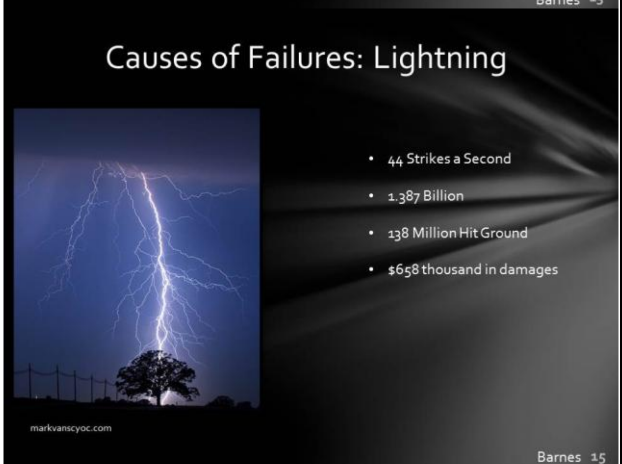
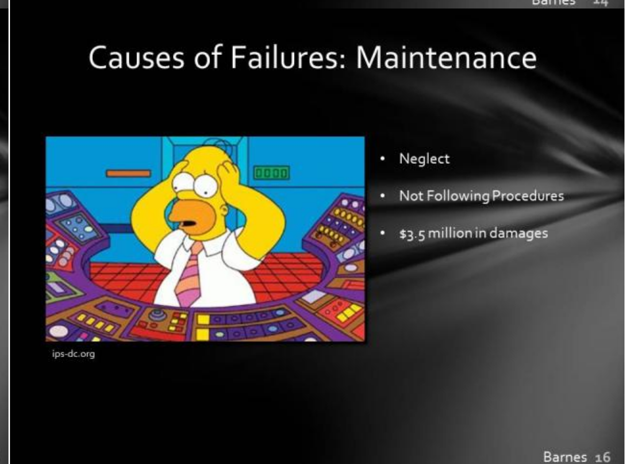
servpkon.org

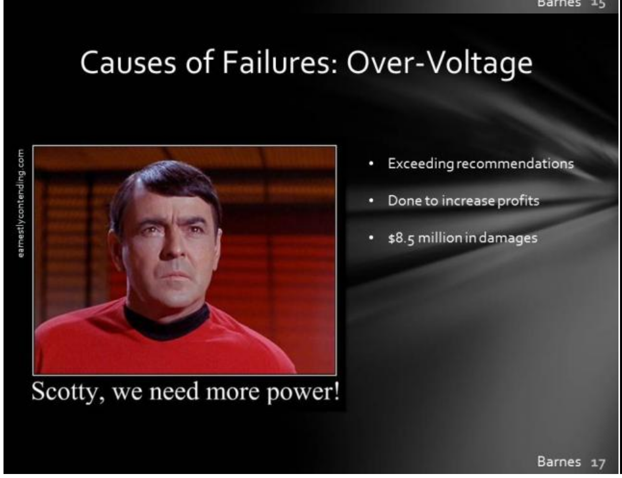
Barnes 12

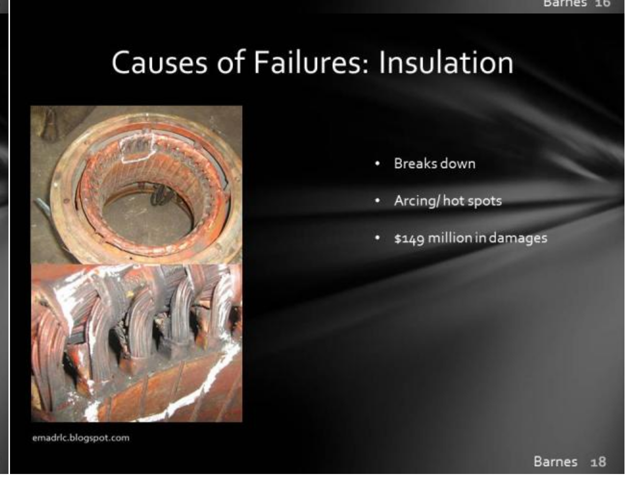

Design: Transformers are Complex
Unit 2 Reactor Building
Unit 1 Reactor Building
Unit 2 Control Room
Unit 1 Control Room
TG-4
TG-3
TG-2
TG-1
kiev2010.com
s3.amazonaws.com
IDEAL TRANSFORMER TEST-Transient-2-Graph
sergi-beigebag.com
Barnes 13

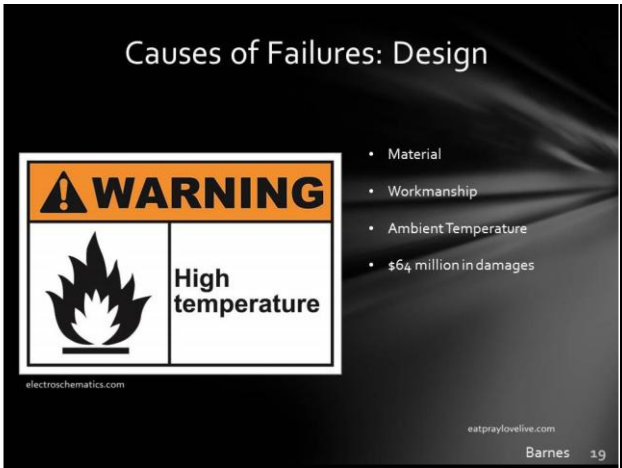

Time
Money
360solutions.com
rhodeislandavene.com
castliphotography.wordpress.com
POWER
BILL
aps
sgssolutions.com
Barnes 14


Causes of Failures: Lightning
• 44 Strikes a Second
• 1.387 Billion
• 138 Million Hit Ground
• $658 thousand in damages
markvanscyoc.com
Barnes 15


Causes of Failures: Maintenance
• Neglect
• Not Following Procedures
• $3.5 million in damages
ips-dc.org
Barnes 16

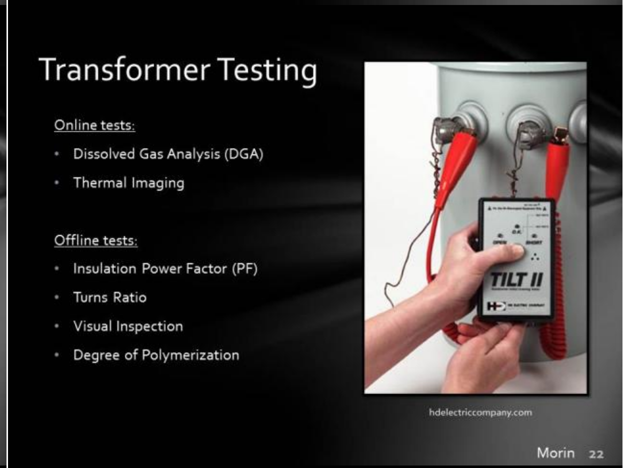

Causes of Failures: Over-Voltage
• Exceeding recommendations
• Done to increase profits
• $8.5 million in damages
earnestlycontending.com
Scotty, we need more power!
Barnes 17

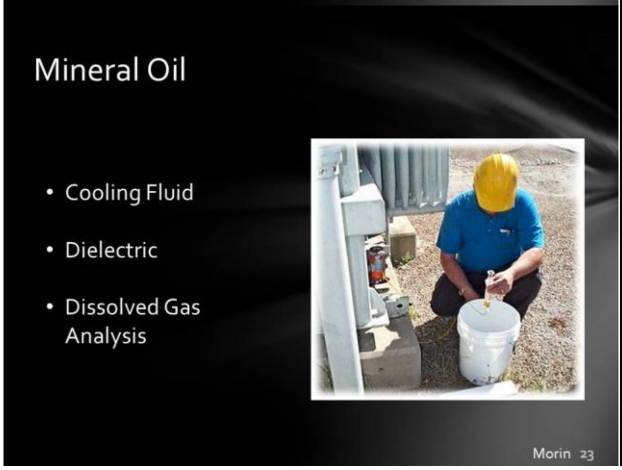

Causes of Failures: Insulation
• Breaks down
• Arcing/ hot spots
• $149 million in damages
emadrlc.blogspot.com
Barnes 18

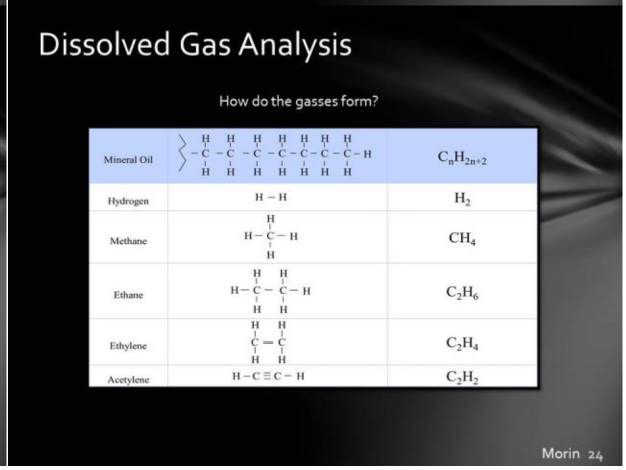

Causes of Failures: Design
WARNING
High temperature
electroschematics.com
Material
Workmanship
Ambient Temperature
$64 million in damages
eatpraylovelive.com
Barnes 19


Failures: Explosions
news.nationalgeographic.com
iwitness.weather.com
Barnes 20

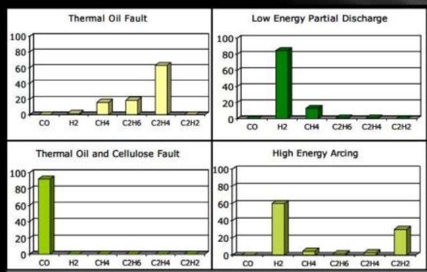

Failures: Fires
sergi-france.com
nttworldwide.com
Barnes 21


Transformer Testing
Online tests:
Dissolved Gas Analysis (DGA)
Thermal Imaging
Offline tests:
Insulation Power Factor (PF)
Turns Ratio
Visual Inspection
Degree of Polymerization
TILT II
hdelectriccompany.com
Morin 22


Mineral Oil
Cooling Fluid
Dielectric
Dissolved Gas Analysis
Morin 23


Dissolved Gas Analysis
How do the gasses form?
Mineral Oil
CnH2n+2
Hydrogen
H2
Methane
CH4
Ethane
C2H6
Ethylene
C2H4
Acetylene
C2H2
Morin 24

Key Gases



Morin 25

Ratio Methods

Rogers' ratio and Dornenburg's ratio

Case	R2 C_2H_2/C_2H_4	R1 CH_4/H_2	R5 C_2H_4/C_2H_6	Suggested fault diagnosis
0	<0.1	>0.1 to <1.0	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Low-energy density arcing—PD*
2	0.1 to 3.0	0.1 to 1.0	>3.0	Arcing—High-energy discharge
3	<0.1	>0.1 to <1.0	1.0 to 3.0	Low temperature thermal
4	<0.1	>1.0	1.0 to 3.0	Thermal <700 °C
5	<0.1	>1.0	>3.0	Thermal >700 °C

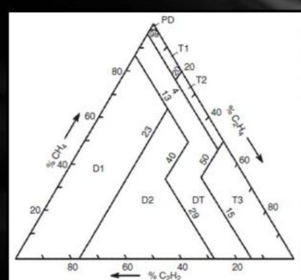
Morin 26

Duval's Triangle

Discharge -Arching
PD- Partial Discharge
D1- Low Energy Discharge
D2- High Energy Discharge

Thermal – General Overheating
T1- Thermal Fault < 300˚c
T2- Thermal Fault 300˚c<T<700˚c
T3- Thermal Fault > 700˚c

DT- Indeterminate



Morin 27

Dissolved Gas Analysis

	A	B	C	D	E	F
1		ppm				
2	Ethylene	218.9954			Doernenburg ratio:	Thermal Fault
3	Hydrogen	52.1718				
4	Methane	107.0636			Rogers ratio:	Thermal Fault<700°C
5	Ethane	137.2955				
6	Acetylene	0.2361			Duval Triangle:	Thermal Fault>700°C
7	CO	31.5989				
8	TDCG	547.3613			Key Gas:	Thermal - Oil
9						
10						

Morin 28

Thermal Imaging

Morin 29

Insulation Power Factor (PF)

- PF refers to the proportion of power being used, to the total product of applied voltage and current.

http://www.pamavtech.com/enroll-now/registration-form-ipf/

Wiedeman 30

Turns Ratio

- The turns ratio test will indicate if two or more of the winding are shorted together

http://www.bridgat.com/transformers-b758_0.html

Wiedeman 31

Visual Inspection

Wiedeman 32

Degree of Polymerization (DP)

- The DP value of the insulating papers is important to the mechanical resistance and , above all, to the short circuit load of transformers.

http://www.lauda-brinkmann.com/apps-polymers.html

Wiedeman 33

Conclusion from Analysis

- Transformer is good for service
- Continue monitoring
- Investigate any sudden changes in DGA

Wiedeman 34

Transformer Condition Report

- We will be giving our client, APS, documentation containing the work we performed during our project.
  - Research
    - Case studies
    - Reasons for failure
    - Transformer condition tests
  - Data Analysis
    - Online Tests
    - Offline Test
  - Conclusion of the transformers condition

Lederhos 35

Budget

Spending limit provided by APS is $2,000

- Verbal agreement, purchases refunded by APS.

Expense breakdown

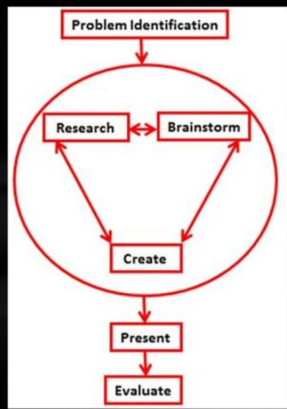
- 4 trips to the Cholla Power Plant
  - Fuel $508
  - Food $170
- Guide to transformer maintenance (Book) $103

Total: $781

Lederhos 36

Design Process

- Problem Identification – 60 hours
  - Initial meeting with client
- Research – 350 hours
  - Reasons for transformers failure
  - Transformer designs
  - Transformer tests
- Brainstorm-140 hours
  - Analysis of data received
- Create – 100 hours
  - Final document to client
- Present – 60 hours
  - Fall and Spring presentations



Lederhos 37

Lessons Learned

- Following the design process helps stay on track
- Good planning, communication, time management
- Adapting to changing client requirements

northtemple.com/2008/10/26/yep

Lederhos 38

Acknowledgements

Client
- Boyd Davis, Arizona Public Service
  Sr. Electrical Engineer, Cholla Power Plant

Technical Advisor
- Tim Vachon, Arizona Public Service
  Consulting Engineer

NAU Faculty
- Dr. David Scott

Lederhos 39

You Are Invited

vectordiary.com/isd_tutorials/009_discoball/discoball_final.gif

To: Our poster presentation

When: April 26, 2013

Where: At the Walkup Skydome during Session III, 2:00pm-4:00pm, on display board 36D

Also please visit our website at:

http://www.cefns.nau.edu/interdisciplinary/d4p/EGR486/EE/13-Projects/Transformer/index.html

or

Google: NAU Autobots

UNDERGRADUATE SYMPOSIUM
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news.nau.edu/wp-content/uploads/2013/04/symposium.jpg

Lederhos 40

Questions???

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