Te Āpiti Generator Investigation

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06/09/2016

Introduction

- Background on Te Āpiti windfarm
- Turbine Set up
- Generator Failures
  - Impact
  - Types of Failure
  - Actions Taken

Background on Te Āpiti

- Commissioned 2004
- 55 x 1.65MW turbines
- 110kV connection to National Grid at Woodville Substation
- Maintenance taken over by Meridian in 2014
- Major Works in the last Year
  - Hub Refurbishment
  - Blade Repairs
  - Gearbox & Generator Replacements

Impact of Generator Failures

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- Time of Failure
- Number of Spares
- Time to refurbish a Unit
- Cost of Refurbishment and Generator Exchange

Time, Cost & Uncertainty. → **Risk**

Turbine Layout (Major Electrical Components)

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Nacelle

- Generator (690 V)

Base

- Thyristors
- Power Factor Correction
- Surge Arrestors
- Generator Circuit Breaker
- Transformer (0.69/22kV)

Our Approach

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• Repair Work	Design and Time Improvements
• History of Units	Contributing factors and patterns
• Condition Monitoring	Trends being monitored online
• Testing	Insulation Condition
• Maintenance	Other turbines components

Previous Failures

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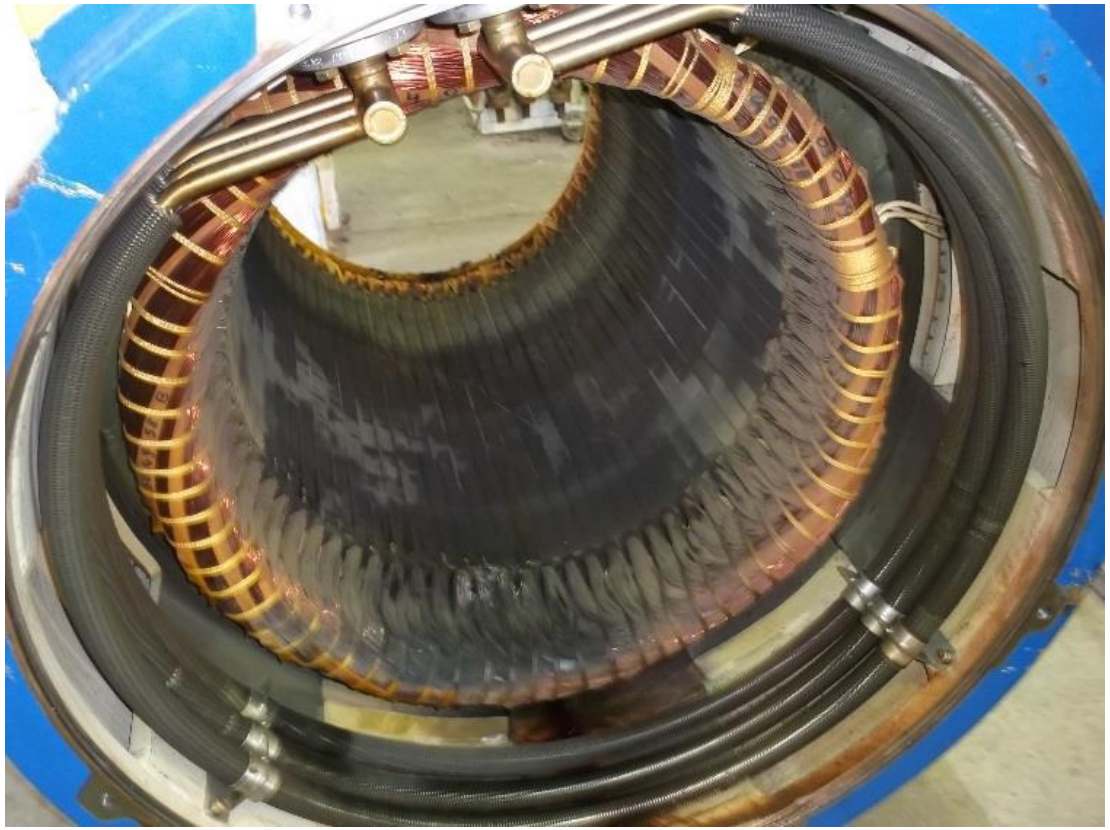
- Squirrel Cage Induction Generator
- Random Wound
- Liquid cooled
- Full Load Power Factor Correction



Previous Failures

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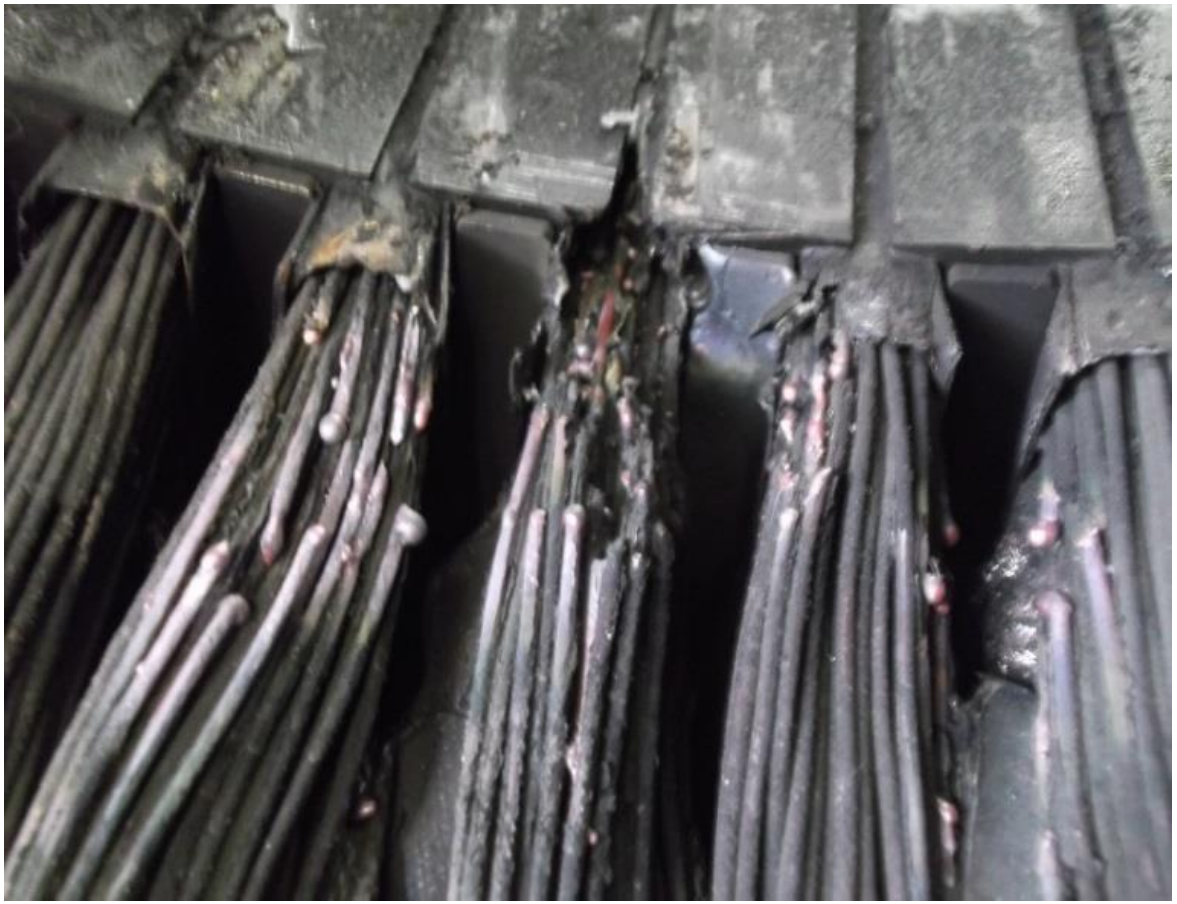
- Vibration of the windings
- Over Voltages
- Contamination
- Abrasion



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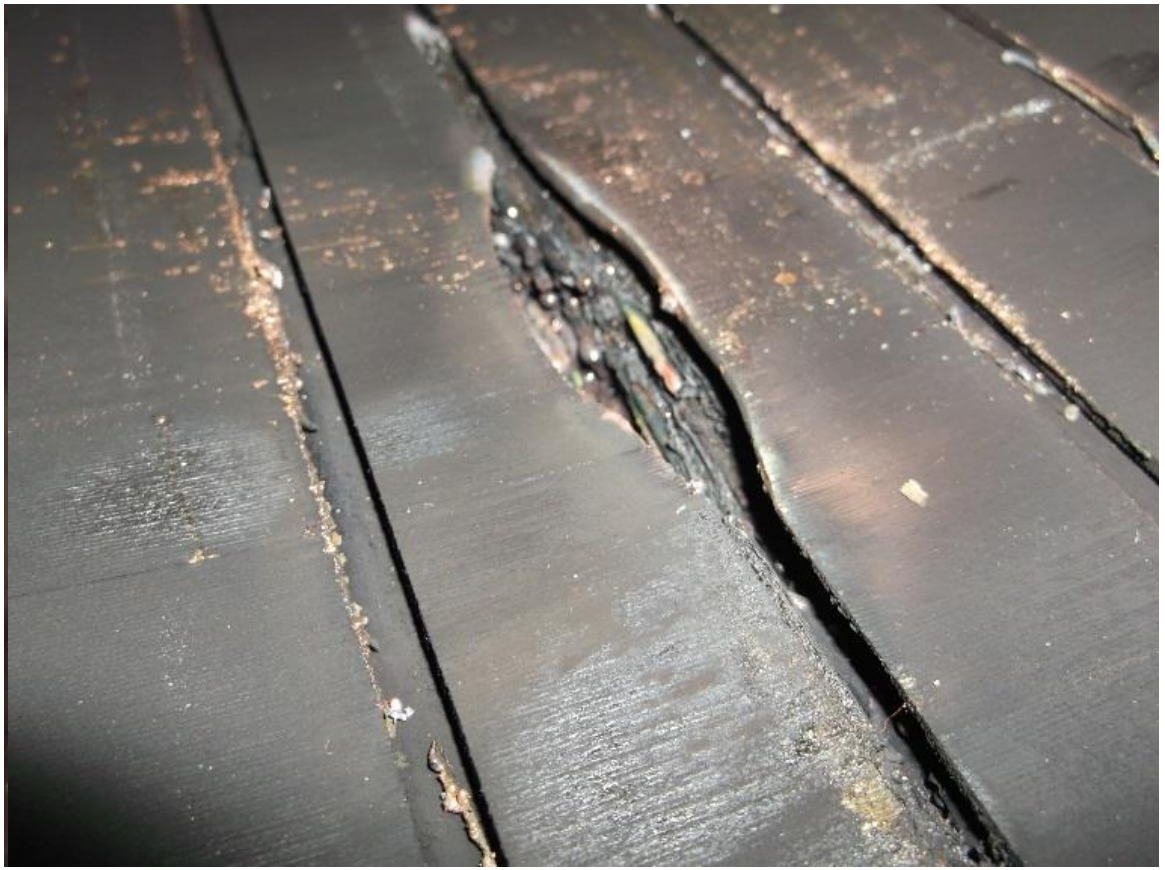
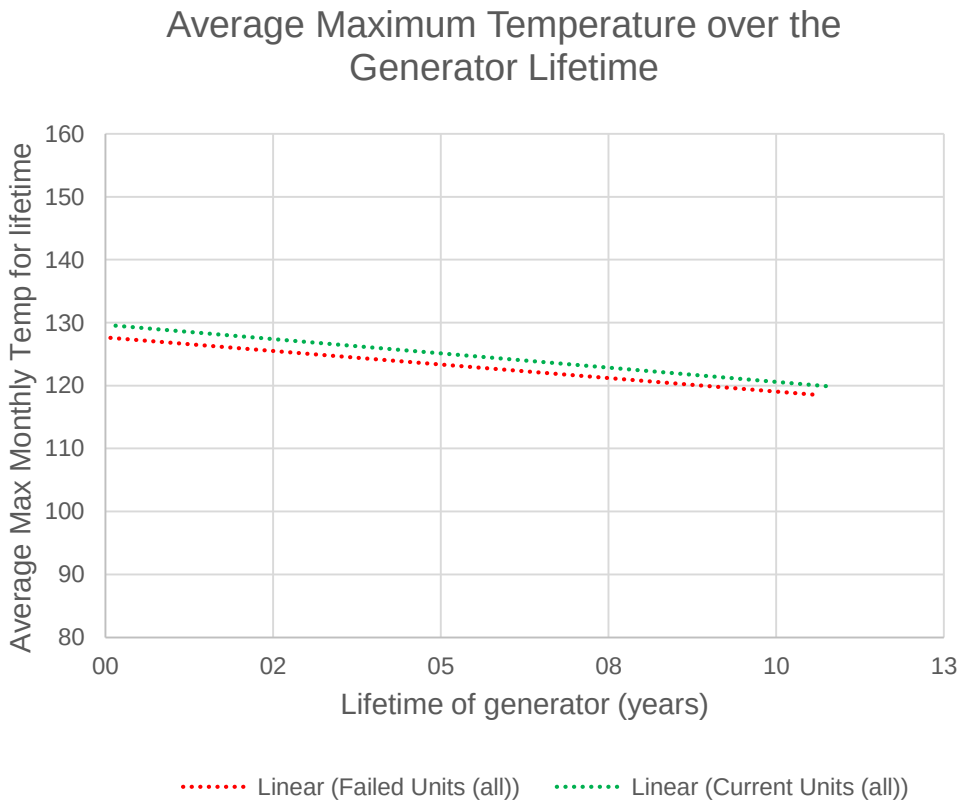
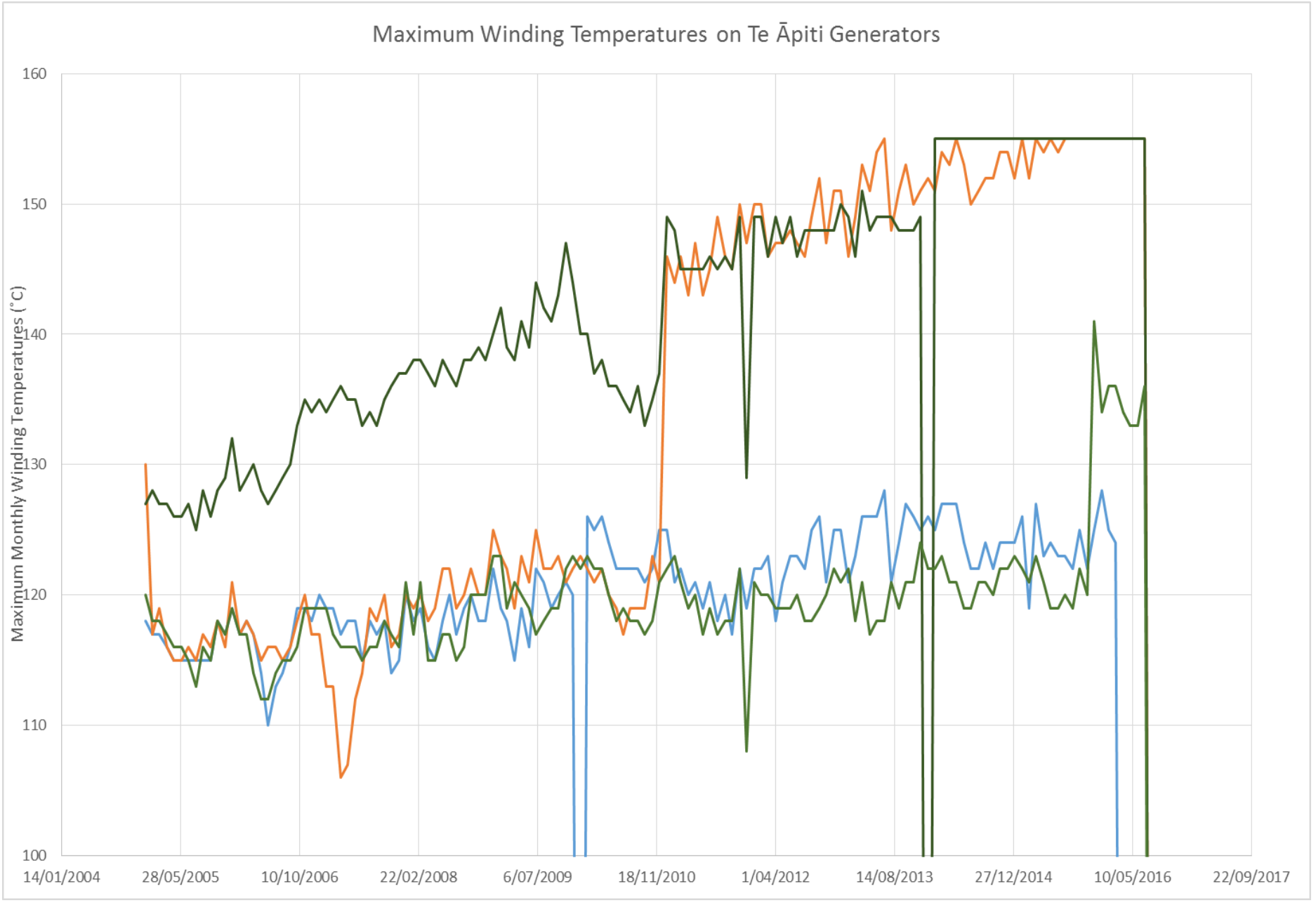


Generator Temperature Trends

- Class F Insulation (155˚C)
- Run to Class B (130˚C)
- Peak Temps between 120˚C and 155 ˚C
- Known issue with some hoses




Maximum Winding Temperatures on Te Āpiti Generators
Maximum Monthly Winding Temperatures (°C)
160
150
140
130
120
110
100
14/01/2004
28/05/2005
10/10/2006
22/02/2008
6/07/2009
18/11/2010
1/04/2012
14/08/2013
27/12/2014
10/05/2016
22/09/2017

Generator Temperature Trends

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Slight correlation with lifetime but…

- Hose Damage
- Rusted fittings
- Coolant Condition
- Generator cooling circulation?

Generator Testing

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What we test with the Baker

- Insulation Resistance & PI
- Step Test
- Surge Test

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

Generator Testing

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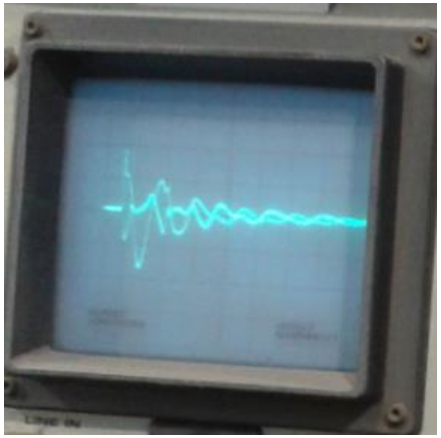
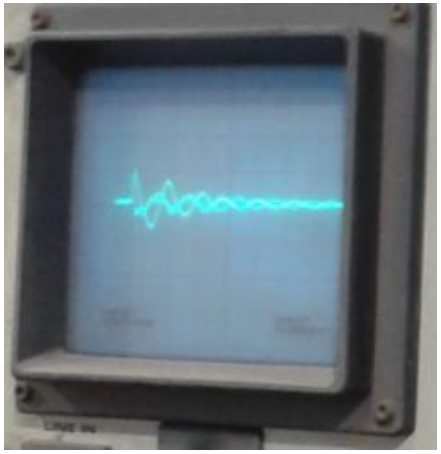
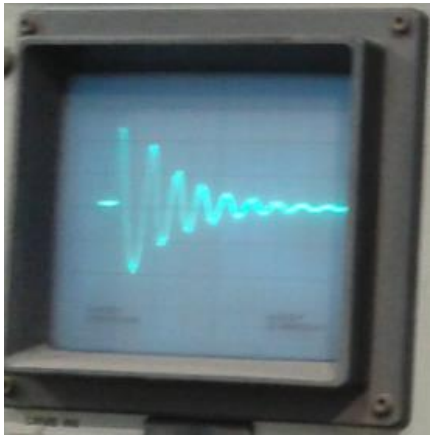
Leads	Lead 1=U1 Lead 3=U2 Lead 2=V2 Earth=V1	Lead 1=U1 Lead 3=U2 Lead 2=W1 Earth=W2	Lead 1=V1 Lead 3=V2 Lead 2=W1 Earth=W2
Test Configuration	Lead2-Lead3 (U-V)	Lead2-Lead3 (U-W)	Lead2-Lead3 (V-W)
Voltage	1.7kV	1.0kV	2.5kV
Result	Fail	Fail	Pass
Screen Shot			

Basic Single Line Diagram

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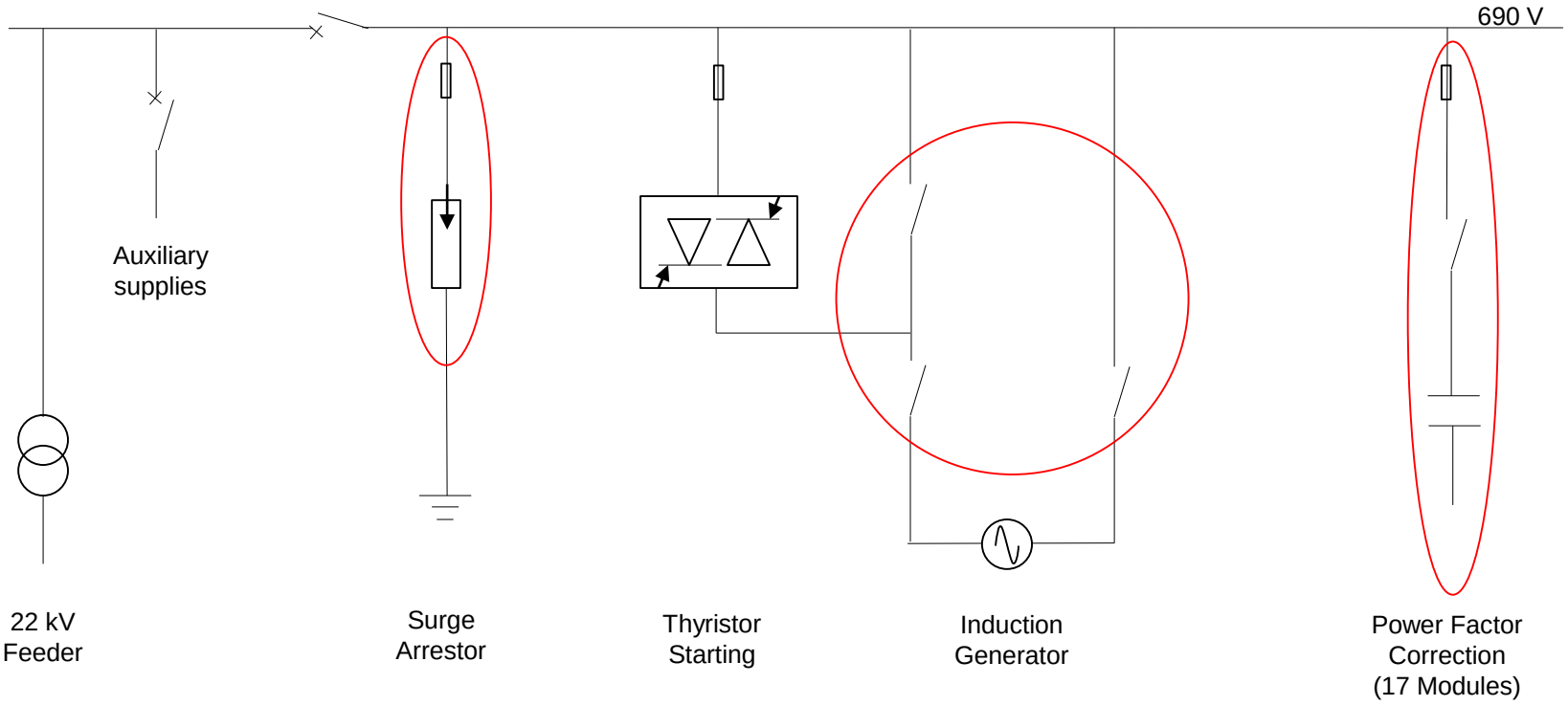
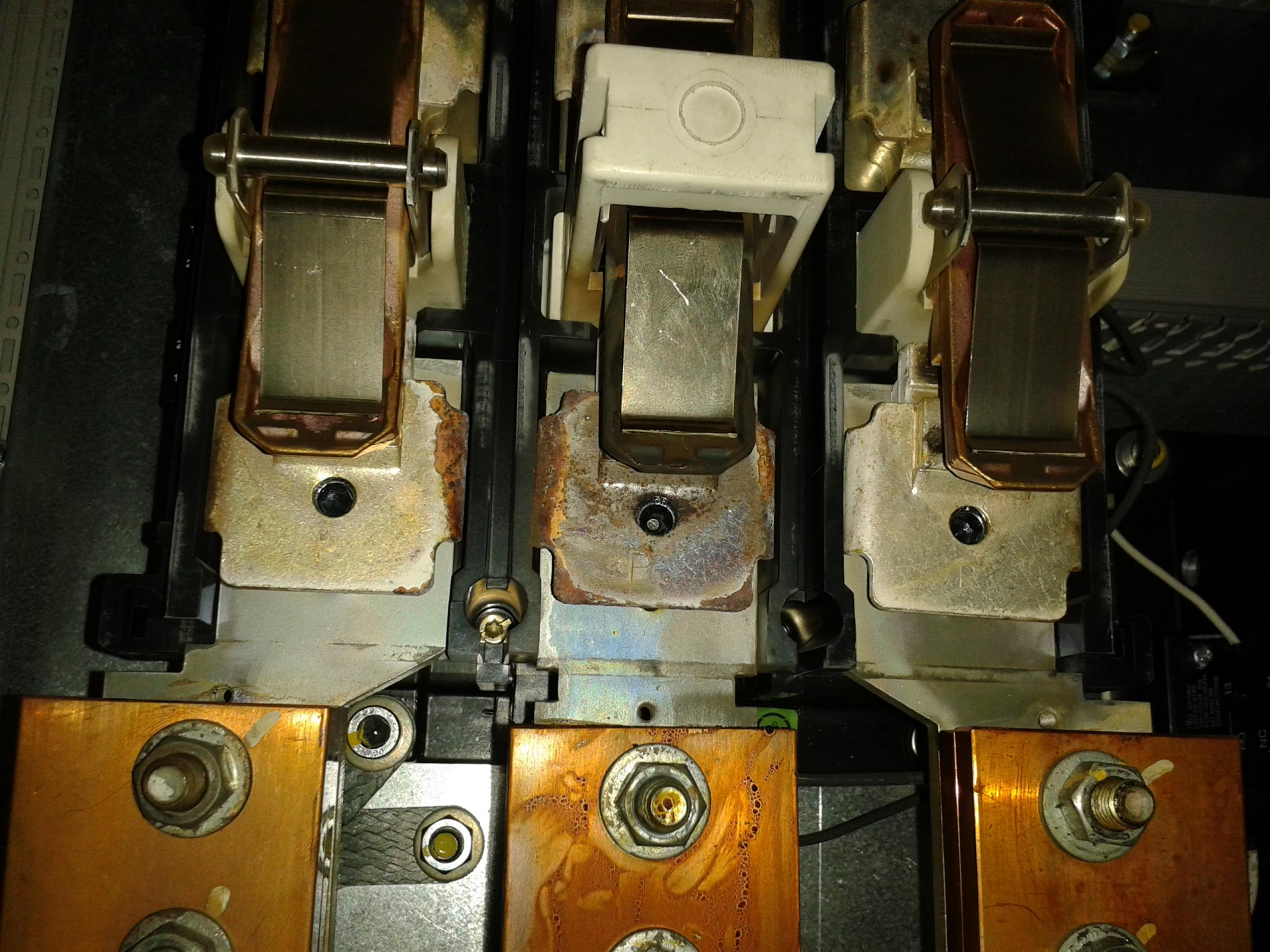



220–240V
50/60 Hz
W 2



Power Factor Correction

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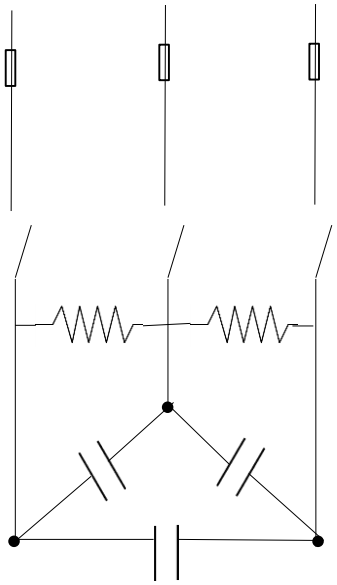
No correlation between step operations and generator failure

But condition could be a factor…

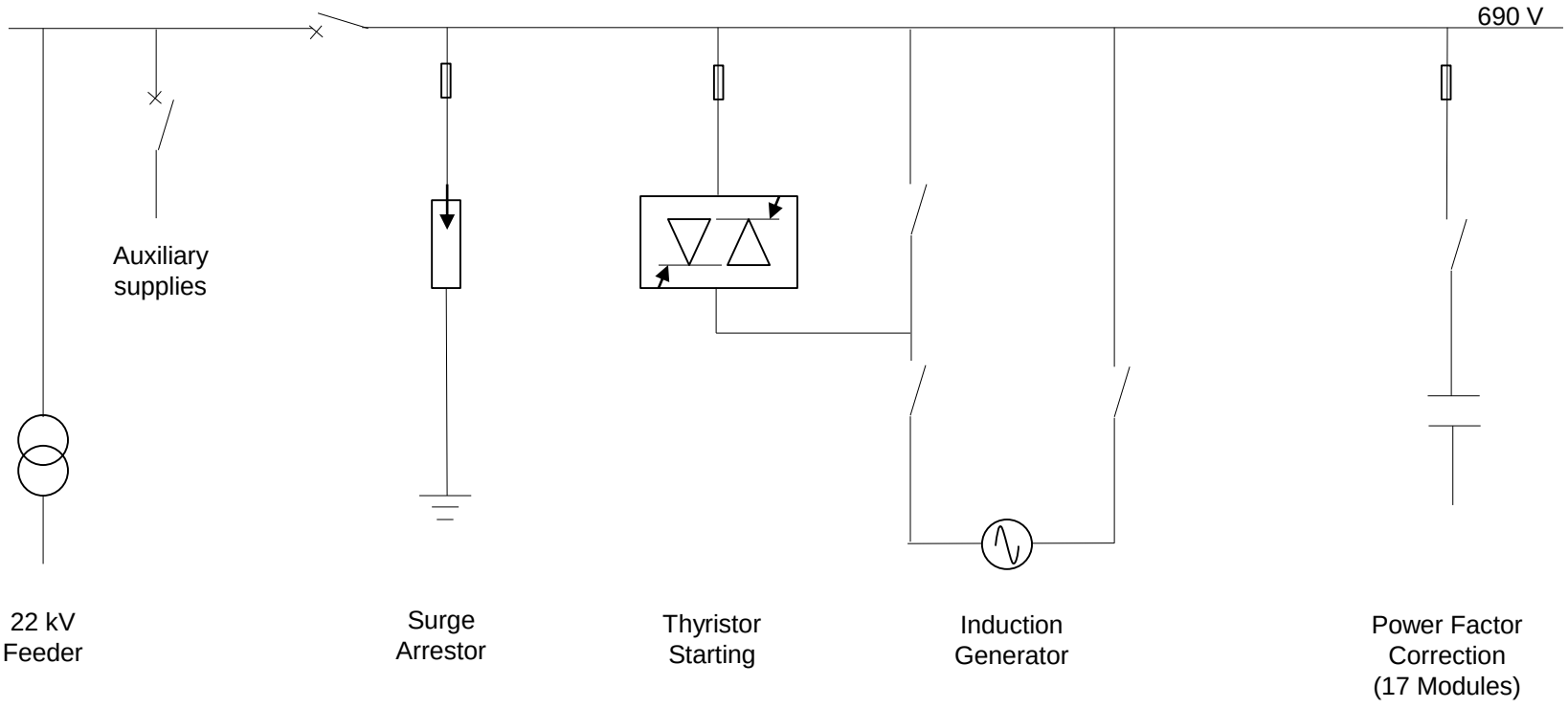
- Capacitors
- Discharge Resistors
- Smoothing Resistors



PFC Module

Turbine Number	PFC UPDATI	Step 1 300kVA	Varianc %	Step 2 250kVA	Varianc %	Step 3 150kVA	Varianc %	Step 4 100kVA	Varianc %	Step 5 50kVAr	Varianc %	Total kVAr	Variance %	Shortfall kVAr	Expecte kVAr	Total Shortfa	Priority order
TAP55	9.5.2016	282.9	94.3	211.2	84.5	130.4	86.9	104.2	104.2	51.9	103.8	780.6	91.8	69.4			
TAP21	13.5.2016	313	104.3	251	100.4	143	95.3	89	89	52	104	848	99.8	2.0			
TAP22	16.5.2016	307	102.3	221	88.4	160	106.7	106	106	52	104	846	99.5	4.0			
TAP28	7.7.2016	283	94.3	221	88.4	140	93.3	96	96	51	102	791	93.1	59.0			
TAP26	2.5.2016	261	87.0	215	86.0	157	104.7	73	73	39	78	745	87.6	105.0			
TAP40		186.6	62.2	184.1	73.6	106.2	70.8	69.8	69.8	34.2	68.4	580.9	68.3	269.1	10200.0	1899.7	1
TAP43	1.6.16	256	85.3	232	92.8	137	91.3	87	87	49.7	99.4	761.7	89.6	88.3			
TAP48		157.1	52.4	197.1	78.8	111.5	74.3	77.1	77.1	41.1	82.2	583.9	68.7	266.1			
TAP24		212.4	70.8	158.3	63.3	107	71.3	76.2	76.2	34.8	69.6	588.7	69.3	261.3			
TAP29		212.8	70.9	172.3	68.9	104.2	69.5	68.5	68.5	32.6	65.2	590.4	69.5	259.6			
TAP47		240.5	80.2	198.3	79.3	74.4	49.6	43.1	43.1	34.2	68.4	590.5	69.5	259.5			
TAP44		218.2	72.7	170.7	68.3	98.1	65.4	72	72	34.6	69.2	593.6	69.8	256.4			
TAP45		210.7	70.2	178.6	71.4	108.4	72.3	65.8	65.8	33.3	66.6	596.8	70.2	253.2			
TAP41		201.4	67.1	171.9	68.8	111.8	74.5	78.6	78.6	34.8	69.6	598.5	70.4	251.5			
TAP54		187	62.3	191	76.4	102	68.0	83.9	83.9	35.2	70.4	599.1	70.5	250.9			
TAP42		215.1	71.7	183.9	73.6	104.5	69.7	67.4	67.4	33.1	66.2	604	71.1	246.0			
TAP14		232.3	77.4	196.5	78.6	102	68.0	53	53	28.4	56.8	612.2	72.0	237.8			
TAP23		221.3	73.8	175	70.0	115.3	76.9	70.7	70.7	34.6	69.2	616.9	72.6	233.1			
TAP30		216.7	72.2	187.2	74.9	108.4	72.3	70.8	70.8	34	68	617.1	72.6	232.9			
TAP37		237	79.0	190.1	76.0	97.7	65.1	66.2	66.2	28.7	57.4	619.7	72.9	230.3	12750.0	3700.7	2
TAP32		196.2	65.4	199	79.6	112.9	75.3	73.5	73.5	40.4	80.8	622	73.2	228.0			
TAP51		228.1	76.0	191.1	76.4	111.2	74.1	61.9	61.9	31.8	63.6	624.1	73.4	225.9			
TAP53		220.1	73.4	195	78.0	110.2	73.5	73.5	73.5	27.3	54.6	626.1	73.7	223.9			
TAP50		203.8	67.9	207.7	83.1	111.4	74.3	80.3	80.3	24.2	48.4	627.4	73.8	222.6			
TAP13		192.2	64.1	208.3	83.3	121.5	81.0	65.7	65.7	41.1	82.2	628.8	74.0	221.2			
TAP20		211.3	70.4	204.3	81.7	113.2	75.5	63.3	63.3	38.1	76.2	630.2	74.1	219.8			
TAP04		220.3	73.4	204.6	81.8	113.5	75.7	72.1	72.1	27.7	55.4	638.2	75.1	211.8			
TAP39		233.2	77.7	187	74.8	108.3	72.2	73.5	73.5	36.2	72.4	638.2	75.1	211.8			
TAP25		229.3	76.4	195.7	78.3	117	78.0	71	71	34.2	68.4	647.2	76.1	202.8			
TAP08		234.1	78.0	199.4	79.8	107.5	71.7	72.3	72.3	37.2	74.4	650.5	76.5	199.5			
TAP05		219	73.0	212	84.8	113.2	75.5	72.6	72.6	34.8	69.6	651.6	76.7	198.4			
TAP27		232.1	77.4	197.4	79.0	115.7	77.1	71.4	71.4	35.3	70.6	651.9	76.7	198.1			
TAP31		245.2	81.7	197.7	79.1	112.8	75.2	67.1	67.1	35.7	71.4	658.5	77.5	191.5			
TAP09		234.1	78.0	210.9	84.4	116.6	77.7	69.7	69.7	32.1	64.2	663.4	78.0	186.6			
TAP18		241	80.3	202.8	81.1	113	75.3	74.5	74.5	33.8	67.6	665.1	78.2	184.9			
TAP36		234.6	78.2	205.9	82.4	117.2	78.1	71.7	71.7	35.9	71.8	665.3	78.3	184.7			
TAP03		243.2	81.1	210.5	84.2	100.9	67.3	72.4	72.4	38.8	77.6	665.8	78.3	184.2			
TAP33		241.3	80.4	203.4	81.4	113.3	75.5	71.7	71.7	36.2	72.4	665.9	78.3	184.1			
TAP34		245.7	81.9	204.3	81.7	105.4	70.3	77	77	36.2	72.4	668.6	78.7	181.4	17850.0	3691.3	3
TAP15		243.2	81.1	197.9	79.2	112.9	75.3	77.1	77.1	40.3	80.6	671.4	79.0	178.6			
TAP11		241.4	80.5	209.9	84.0	112.7	75.1	73.4	73.4	34.5	69	671.9	79.0	178.1			
TAP12		246.5	82.2	202.5	81.0	113.2	75.5	75.5	75.5	35.4	70.8	673.1	79.2	176.9			
TAP10		255.4	85.1	197.6	79.0	112.3	74.9	76.2	76.2	33.4	66.8	674.9	79.4	175.1			
TAP19		240.6	80.2	202.1	80.8	121.8	81.2	78.7	78.7	39.4	78.8	682.6	80.3	167.4			
TAP07		256.2	85.4	210.8	84.3	103.9	69.3	76.9	76.9	35.4	70.8	683.2	80.4	166.8			
TAP16		243.7	81.2	217.2	86.9	116.3	77.5	77.6	77.6	43.9	87.8	698.7	82.2	151.3			
TAP06		246.6	82.2	218.9	87.6	119.5	79.7	78.8	78.8	35.9	71.8	699.7	82.3	150.3			
TAP46		245.5	81.8	220.9	88.4	137.6	91.7	87.9	87.9	20	40	711.9	83.8	138.1			
TAP02		299.3	99.8	209.9	84.0	116.4	77.6	76.1	76.1	35.8	71.6	737.5	86.8	112.5			

Preventative Maintenance



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Summary

- Base test of all generators on the farm
- Testing generator subsystems on installation
- Maintenance Plans
- Improving our response plan

Questions or Suggestions…?