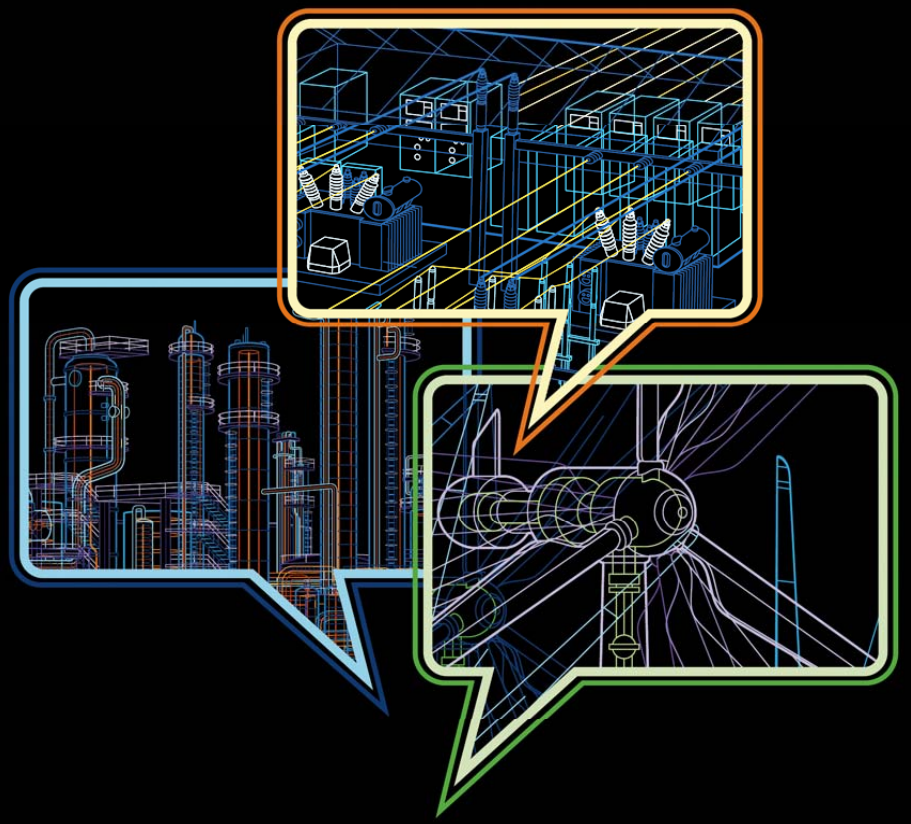

**ABB Automation & Power World: April 18-21, 2011**

# WPS-131-1
# Reliability Based Transmission System Planning

# WPS-131-1
# Reliability Based Transmission System Planning

- Speaker name: Bob Reymers
- Speaker title: Project Development Manager
- Company name: ABB Turnkey Substation Group
- Location: Raleigh, NC

**Co-presenter**

- Speaker name: Krassimir Kutlev
- Speaker title: Consultant
- Company name: ABB Consulting Group
- Location: Raleigh, NC

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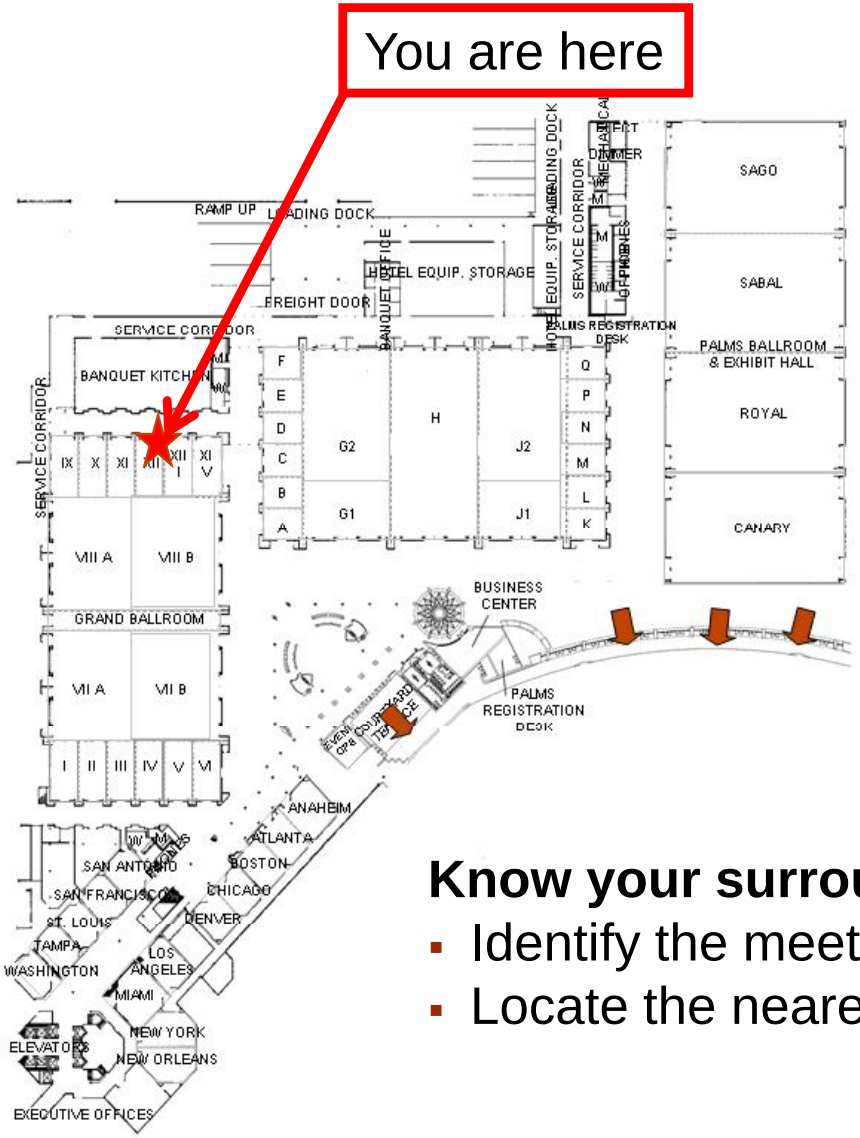


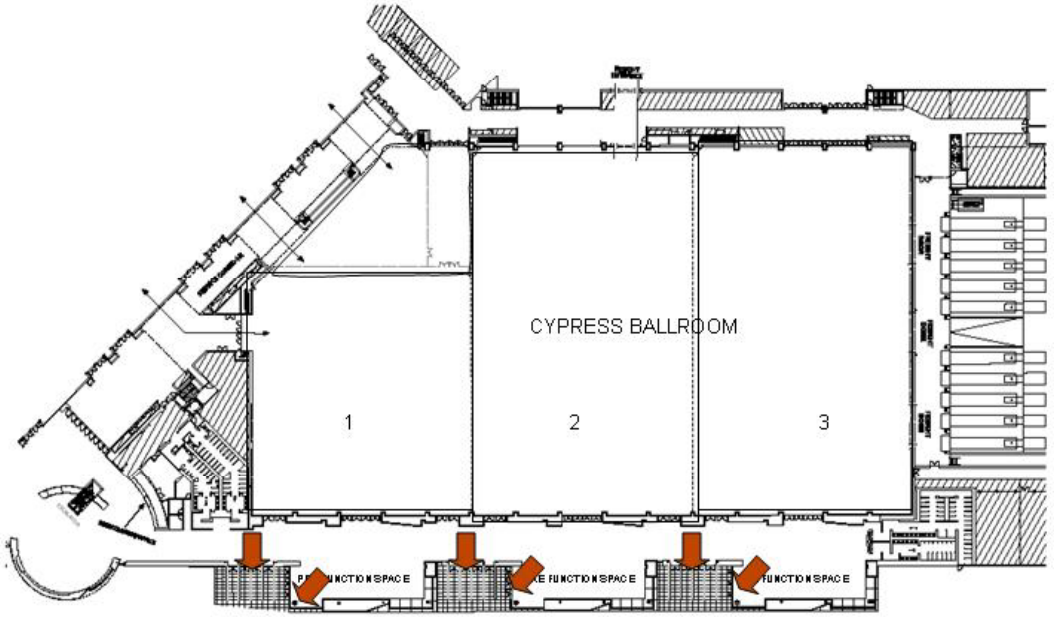


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# Agenda

- Project Objective
- Project Tasks
- Project Results
- Next Steps

# Project Objective

- Model a selected subsystem of the utility sub-transmission system
- Confirm that subsystem reliability could be determined and dollarized
- Confirm that impact on reliability of various investment alternatives can be quantified.

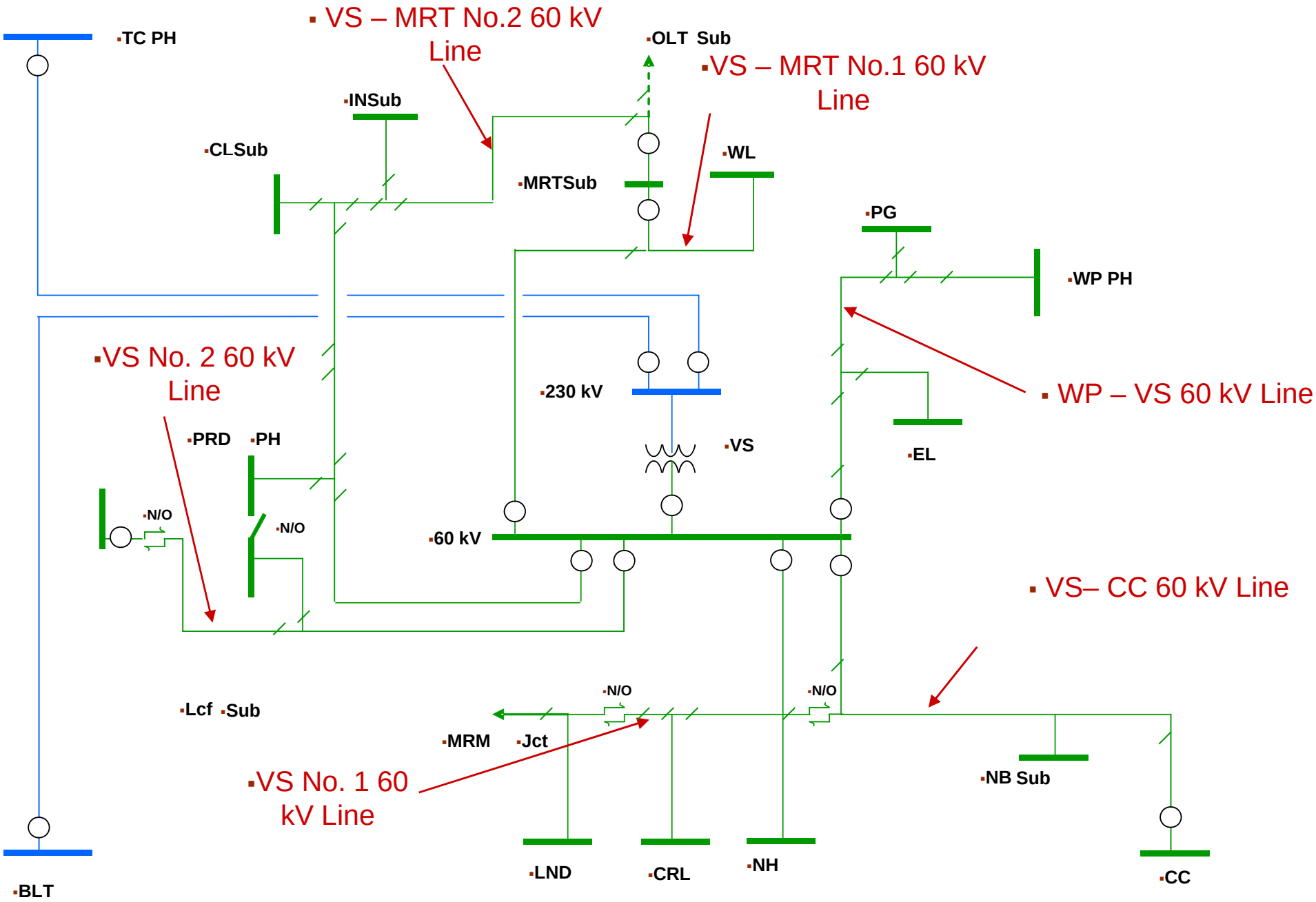
# Project Tasks

- Task 1 - Network Selection and Options Identification
- Task 2 – Network Modeling
- Task 3 – Model Benchmarking with Utility Data
- Task 4 – Performance of Reliability Analysis
- Task 5 – Investment Option Assessments

# Task One – Selection of Network and Options

- Network Selection
  - Network Selected
- Investment Option Selection
  - No Predetermined Options Identified
  - Options Identified Based on Model Output
- Obtained Data Needed for Model Benchmarking

# VS 60 kV System



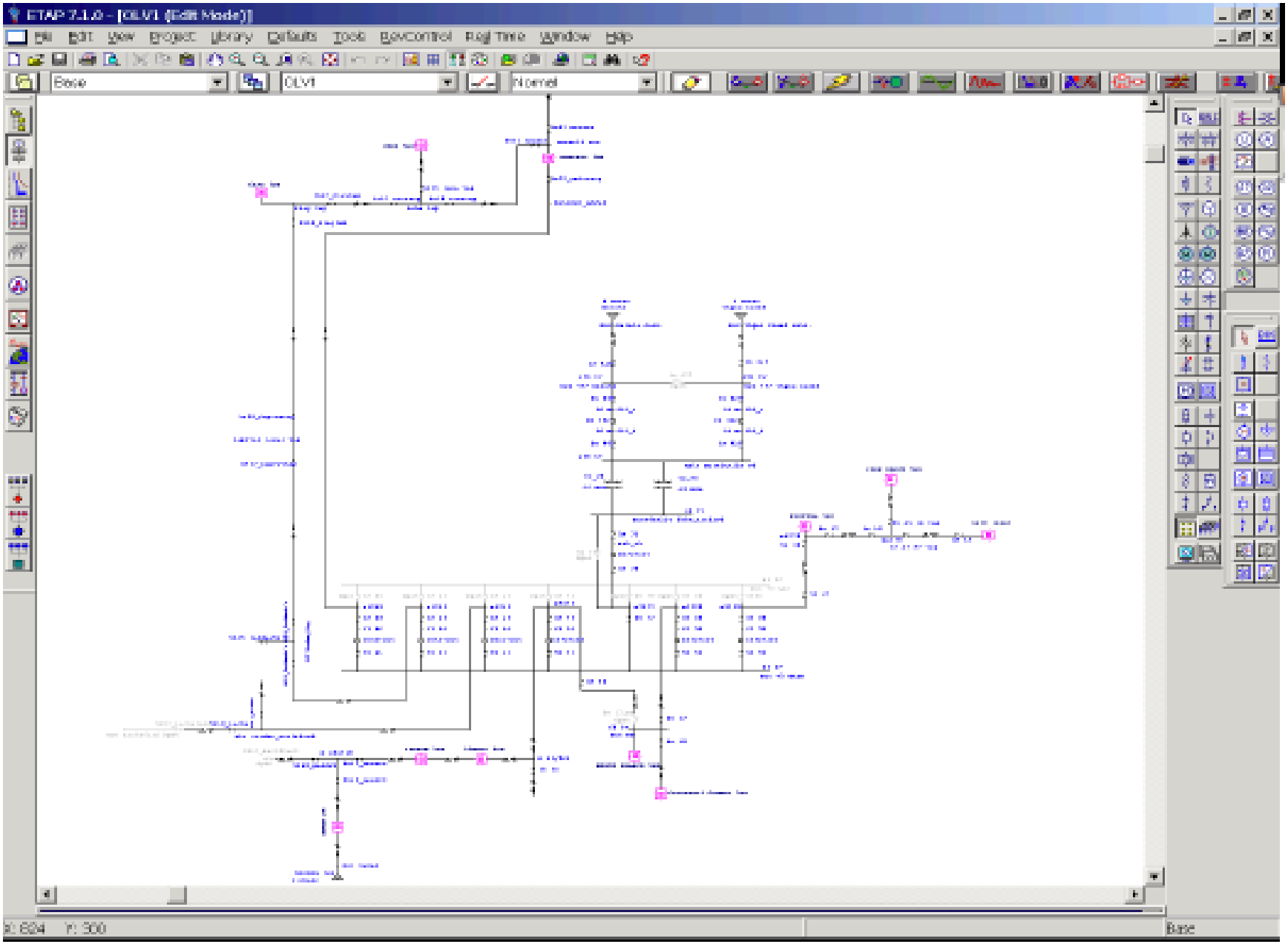
# Task Two – Selection of ETAP

- Publicly Available Software
- Models Networks and Substations
- Uses Industry (CIGRE, CEA, IEEE) and/or Customer Specific Reliability Data
- Determines Failure Rates at All Modeled Points
- Calculates Reliability Indices
  - System Level – SAIFI, SAIDI, EENS, ECOST, etc.
  - Load Level – Outage Frequency, Outage Durations, EENS, ECOST etc.
- Cost Competitive
- Widely Used and Supported

# Reliability Results – System Related

- PUC Focused:
  - SAIFI - System Average Interruption Frequency Index
    - Average Number of Interruptions per Customer per Year
  - SAIDI - System Average Interruption Duration Index
    - Average Interruption Duration per Customer per Year
  - CAIDI - Customer Average Interruption Duration Index
    - Average Hours per Interruption
- Shareholder Focused:
  - EENS - System Expected Energy Not Supplied Index
    - Megawatt Hours per Year
- Customer Focused:
  - ECOST - System Expected Interruption Cost
    - Customer Interruption Costs per Year (IEEE or Utility Specific)

# ETAP Model of VS System



# Task Three - Model Benchmarking

- Data Needed for Benchmarking
  - Single Line Diagrams (SLD's)
  - Substation Equipment Data (Age, Type)
  - Overhead Lines
  - Loads/Feeders information
  - Current Utility System Reliability Indices
- Reliability Data Needed
  - Failure Rates for Substation Components and Overhead Lines
    - Component Outage Records, System Outage Records
  - Mean Time to Replace or Repair, Mean Time to Switch, Maintenance Frequency
- Iterations Performed to Match Existing System Reliability Indices

# Reliability Model Benchmarking Iterations

1. **First Iteration**
   - Preliminary Configuration for VS with OHL Outages
   - All Interruptions for One Minute and Over Considered
2. **Second Iteration**
   - 60 kV OHL Line Lengths Corrected
   - 60 kV OHL Outages with Durations Between 1 to 3 Minutes Eliminated
   - Back Up Power Supply for VS System Considered
3. **Third Iteration**
   - Prorated Failure Rate Based on Circuit Breaker Age
   - Failure Rate Based on Transformer Age (No Correlation Noted, Change Deleted)
   - MTTS Corrected Based on SCADA Availability
   - Remove the Spare Transformer for LND
   - MTT Replace for Transformers Changed to 120 Hours
   - MTT Replace for Breakers and Switches Changed to 80 Hours
   - MTTR for Breakers Changed to 12 Hours
   - Obtained Information About Installation Date of CB 12 at WP Sub
4. **Fourth Iteration**
   - Increase MTTR for Equipment According to Industry Standards
   - Breakers (24 Hours), Transformers (120/40 Hours for 3/1PH), Switches (16 Hours)
5. **Fifth Iteration**
   - Disconnect WP Generation Sub from the rest of the system
   - Decrease MTTR for Transformers back to 72 hr for 3 phases and 24 hr for 1 phase; LTC - 24 hr
   - Decrease MTTR for CB to 20 hr for 60 kV & 22 hr for 230 kV
   - Decrease MTTR for switches to 12 hr - 60 kV and to 14 hr - 230 kV

# Task Four – Performance of Reliability Analysis

- Load Point Related
  - Reliability Indices at Any Load Point on Single Line Diagram
- System Related - Impact on EENS and ECOST
  - For Entire System
    - Ranking Components Contribution
    - Ranking Substation Contribution – VS, PG, etc.
    - Ranking Components Types Contribution – OHL, transformers, circuit breakers, etc.
  - High Impact Loads - Loads Feeding Selected Customers, e.g., PG Sub
    - Ranking Components Contribution to the High Impact Loads

# Task Four – Opportunities for Investment

- "Locational" Impacts on EENS and ECOST
  - Sort by System Location
    - Sum for All Components in Specific Location
    - E.g., PG Substation
  - Look for High Impact Locations
- Component Impacts on EENS and ECOST
  - Sort by System Component
    - E.g. all transformers > x Years old
    - E.g. all Oil Circuit Breakers
  - Look for High Impact Component Groups

# Impact Sorted by System Component

## EENS (MWhrs/year)

| | | | |
|---|---|---|---|
| 1 | T1_VS | Xfmr2 | 222.035 |
| 2 | Main Bus+2A+2CT VS | Bus | 102.422 |
| 3 | Line VS_EL | Line | 101.007 |
| 4 | T2_VS | Xfmr2 | 74.012 |
| 5 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 47.641 |
| 6 | Line EL_PG_JCT | Line | 37.387 |
| 7 | CB32+2CT | PD | 20.804 |
| 8 | Line PG Jct_WP | Line | 19.253 |
| 9 | T1 MRT | Xfmr2 | 18.982 |
| 10 | T1 LND | Xfmr2 | 17.112 |
| 11 | T1 MRM | Xfmr2 | 16.267 |
| 12 | Line PG Tap | Line | 15.217 |
| 13 | T1 CL | Xfmr2 | 13.811 |
| 14 | T1_EL | Xfmr2 | 12.855 |
| 15 | T1_CRL | Xfmr2 | 12.394 |
| 16 | CB42+2CT | PD | 11.281 |
| 17 | T2 PG | Xfmr2 | 11.113 |
| 18 | SW 41 | PD | 11.073 |
| 19 | SW 11 | PD | 11.073 |
| 20 | SW 61 | PD | 11.073 |
| 21 | SW 71 | PD | 11.073 |
| 22 | SW 73 | PD | 11.073 |
| 23 | SW 77 | PD | 11.073 |
| 24 | SW 21 | PD | 11.073 |
| 25 | SW 51 | PD | 11.073 |
| 26 | SW 31 | PD | 11.073 |
| 27 | T1 PG | Xfmr2 | 10.036 |
| 28 | T1 CC | Xfmr2 | 9.640 |
| 29 | Bus VS MAIN | Bus | 9.324 |
| 30 | T1 IN | Xfmr2 | 8.572 |

## ECOST ($/Year)

| | | | |
|---|---|---|---|
| 1 | T1_VS | Xfmr2 | 1,140,231 |
| 2 | Main Bus+2A+2CT VS | Bus | 496,184 |
| 3 | Line VS_EL | Line | 406,235 |
| 4 | T2_VS | Xfmr2 | 371,467 |
| 5 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 230,800 |
| 6 | Line EL_PG_JCT | Line | 143,847 |
| 7 | T1 MRT | Xfmr2 | 118,711 |
| 8 | CB32+2CT | PD | 92,720 |
| 9 | T1 CL | Xfmr2 | 85,518 |
| 10 | T1 MRM | Xfmr2 | 66,695 |
| 11 | T1_EL | Xfmr2 | 66,167 |
| 12 | T1 IN | Xfmr2 | 63,290 |
| 13 | Line PG Tap | Line | 61,442 |
| 14 | Line PG Jct_WP | Line | 60,652 |
| 15 | T1 PG | Xfmr2 | 60,523 |
| 16 | SW 71 | PD | 52,675 |
| 17 | SW 73 | PD | 52,675 |
| 18 | SW 61 | PD | 52,675 |
| 19 | SW 11 | PD | 52,675 |
| 20 | SW 31 | PD | 52,675 |
| 21 | SW 41 | PD | 52,675 |
| 22 | SW 51 | PD | 52,675 |
| 23 | SW 77 | PD | 52,675 |
| 24 | SW 21 | PD | 52,675 |
| 25 | T2 PG | Xfmr2 | 47,649 |
| 26 | T1 CC | Xfmr2 | 46,589 |
| 27 | Bus VS MAIN | Bus | 44,358 |
| 28 | T1 LND | Xfmr2 | 40,445 |
| 29 | T1_CRL | Xfmr2 | 39,017 |
| 30 | TSpare MRT | Xfmr2 | 38,713 |

# Impact Sorted by Location

EENS (MWhrs/year)

| | | |
|---|---|---|
| 1 | VS | 638.626 |
| 2 | OHL | 196.920 |
| 3 | OHL Switches | 36.939 |
| 4 | MRT | 35.366 |
| 5 | PG | 28.903 |
| 6 | MRM | 28.405 |
| 7 | CRL | 28.179 |
| 8 | CL | 25.285 |
| 9 | LND | 24.711 |
| 10 | EL | 19.658 |
| 11 | IN | 12.195 |
| 12 | CC | 11.743 |
| 13 | OLT | 11.062 |
| 14 | NB | 7.718 |
| 15 | WP | 4.815 |

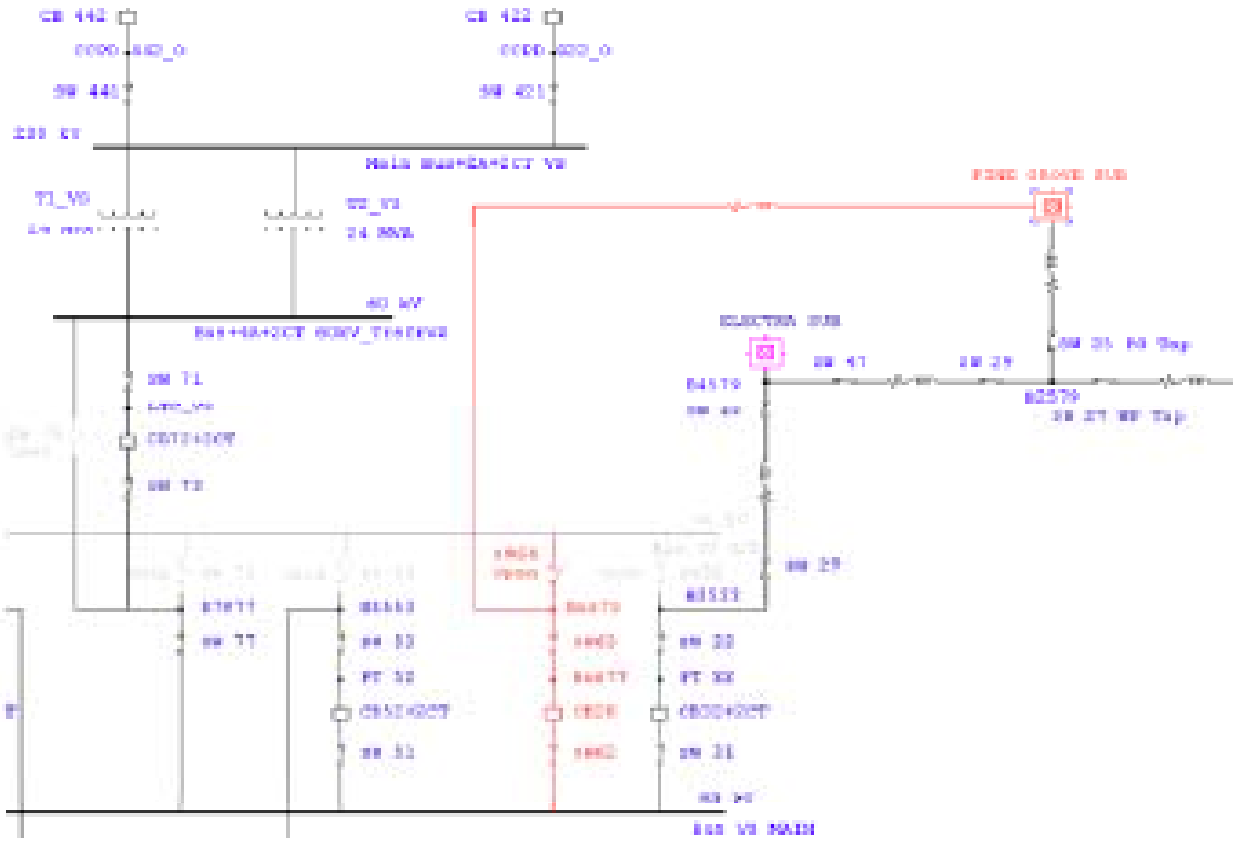
ECOST ($/year)

| | | |
|---|---|---|
| 1 | VS | 3,084,866 |
| 2 | OHL | 795,402 |
| 3 | MRT | 216,690 |
| 4 | OHL Switches | 155,780 |
| 5 | PG | 143,129 |
| 6 | CL | 141,889 |
| 7 | MRM | 104,470 |
| 8 | EL | 97,144 |
| 9 | IN | 87,026 |
| 10 | CRL | 86,303 |
| 11 | LND | 61,244 |
| 12 | CC | 55,665 |
| 13 | OLT | 53,929 |
| 14 | NB | 42,400 |
| 15 | WP | 15,160 |

# Task 5 – Investment Option Assessments

- **Alternative 1** - New 60kV OHL between VS & PG Substations
- **Alternative 2** - New 60 kV OHL from MRT Substation to PG Substation
- **Alternative 3** - New 230 kV OHL from TC Substation to PG Jct., with New 230/60 kV Substation
- **Alternative 4** – Upgraded VS Substation

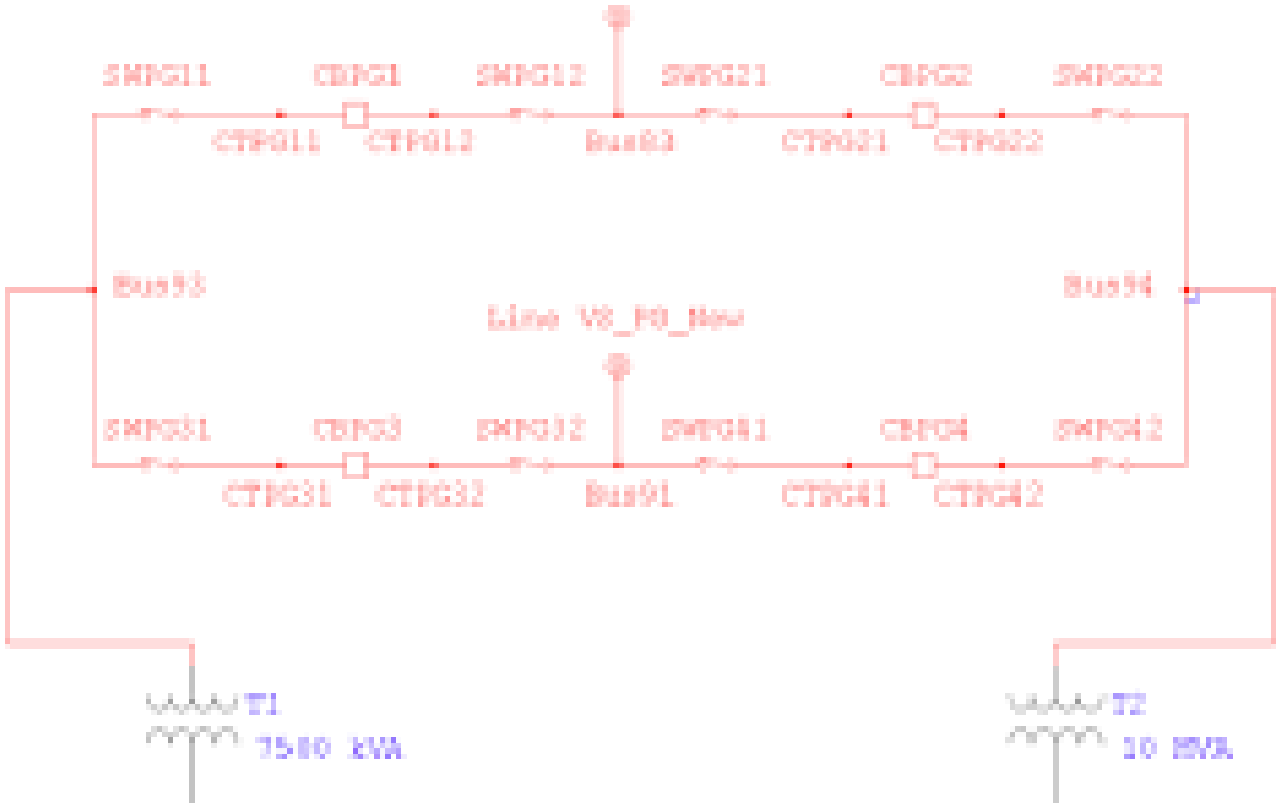
# Alternative 1 – New VS – PG OHL



New 15 mile 60 kV OHL Connecting VS Sub with PG Sub

Additional Circuit Breaker Bay in VS Sub

# Alternative 1 - New VS – PG OHL




PG 60 kV Switchyard Rebuilt from Collector Bus to Ring Bus

# Alternative 1 – Reliability Results at PG, WP, EL

- All additional equipment are considered new – Open Sources & Benchmarked reliability data
- The new OHL can supply loads for PG, WP & EL Substations

| Bus/Load | Load Sector | W/ New OHL VS-PG | | W/o New OHL VS-PG | |
|---|---|---|---|---|---|
| | | Average Interrupting Rate | Annual Outage Duration | Average Interrupting Rate | Annual Outage Duration |
| ID | | f / yr | hr / yr | f / yr | hr / yr |
| Bus PG1101 | N/A | 0.5951 | 7.37 | 1.7447 | 16.43 |
| Bus PG1102 | N/A | 0.5984 | 7.45 | 1.7494 | 16.52 |
| Bus WP1101 | N/A | 1.7550 | 10.76 | 1.7508 | 16.18 |
| Bus WP1103 | N/A | 1.7536 | 10.76 | 1.7494 | 16.18 |
| Bus EL1101 | N/A | 1.7536 | 10.15 | 1.7494 | 13.85 |
| Bus EL1102 | N/A | 1.7536 | 10.15 | 1.7494 | 13.85 |

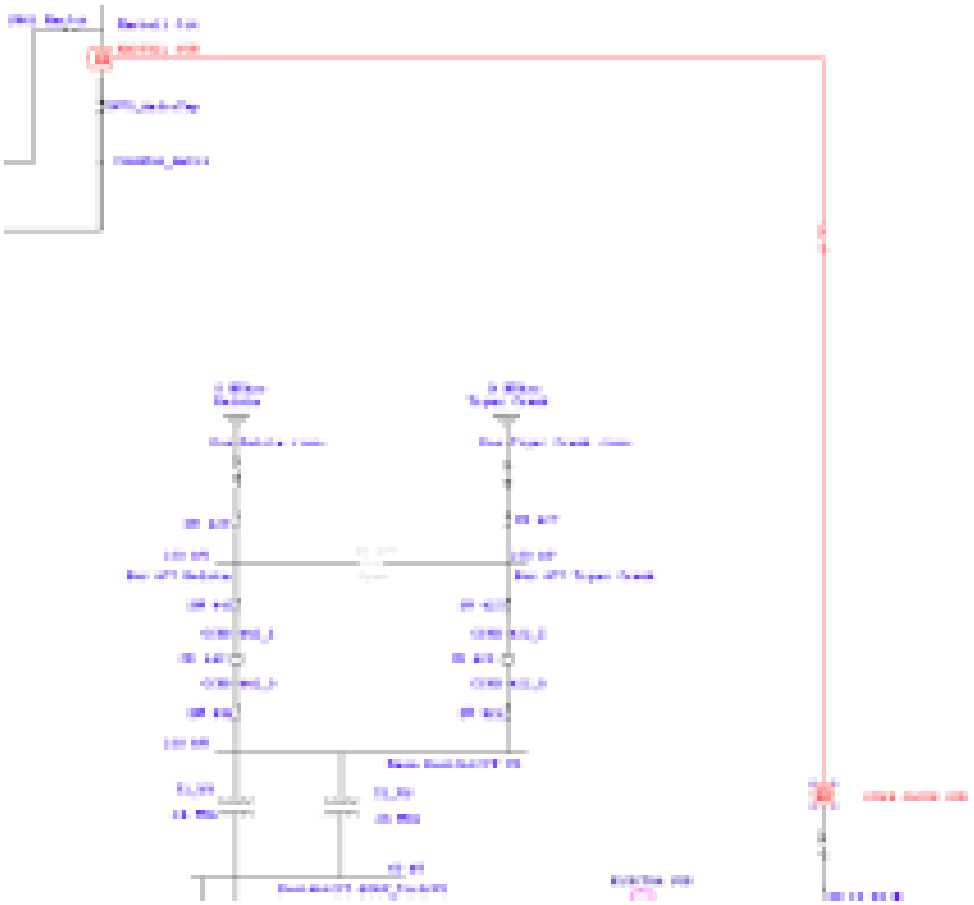
# Alternative 1 – PG 12 kV buses ECOST

| | With New OHL from VS to PG | | | | | | Without direct OHL from VS to PG | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Contributing Element | | ECOST | Contributing Element | | ECOST | Contributing Element | | ECOST | Contributing Element | | ECOST |
| No | ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr |
| 1 | Bus PG1101 | | 254,166 | Bus PG1102 | | 191,864 | Bus PG1101 | | 546,381 | Bus PG1102 | | 400,433 |
| 2 | T1_VS | Xfmr2 | 65,505 | T1_VS | Xfmr2 | 51,363 | Line VS_EL | Line | 124,966 | Line VS_EL | Line | 89,736 |
| 3 | Main Bus+2A+2CT VS | Bus | 48,472 | Main Bus+2A+2CT VS | Bus | 36,959 | T1_VS | Xfmr2 | 65,505 | T1_VS | Xfmr2 | 51,363 |
| 4 | T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 | Line EL_PG JCT | Line | 59,836 | Line EL_PG JCT | Line | 42,967 |
| 5 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 22,547 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 17,192 | Main Bus+2A+2CT VS | Bus | 48,472 | Main Bus+2A+2CT VS | Bus | 36,959 |
| 6 | T2_VS | Xfmr2 | 21,205 | T2_VS | Xfmr2 | 16,278 | T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 |
| 7 | Bus VS MAIN | Bus | 4,353 | Bus VS MAIN | Bus | 3,285 | Line PG Tap | Line | 31,069 | Line PG Tap | Line | 22,310 |
| 8 | SW 71 | PD | 3,789 | SW 71 | PD | 2,807 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 22,547 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 17,192 |
| 9 | SW 73 | PD | 3,789 | SW 73 | PD | 2,807 | T2_VS | Xfmr2 | 21,205 | T2_VS | Xfmr2 | 16,278 |
| 10 | SW 61 | PD | 3,789 | SW 61 | PD | 2,807 | CB32+2CT | PD | 20,065 | CB32+2CT | PD | 15,299 |
| 11 | SW 11 | PD | 3,789 | SW 11 | PD | 2,807 | Line PG Jct_WP | Line | 13,282 | Line PG Jct_WP | Line | 6,483 |
| 12 | SW 31 | PD | 3,789 | SW 31 | PD | 2,807 | Bus VS MAIN | Bus | 4,353 | Bus VS MAIN | Bus | 3,285 |
| 13 | SW 41 | PD | 3,789 | SW 41 | PD | 2,807 | SW 71 | PD | 3,789 | SW 71 | PD | 2,807 |
| 14 | SW 51 | PD | 3,789 | SW 51 | PD | 2,807 | SW 73 | PD | 3,789 | SW 73 | PD | 2,807 |
| 15 | SW 77 | PD | 3,789 | SW 77 | PD | 2,807 | SW 61 | PD | 3,789 | SW 61 | PD | 2,807 |
| 16 | SW 21 | PD | 3,789 | SW 21 | PD | 2,807 | SW 11 | PD | 3,789 | SW 11 | PD | 2,807 |
| 17 | CB 422 | PD | 2,963 | LTC PG2 | PD | 2,115 | SW 45_E | PD | 3,789 | SW 45_E | PD | 2,807 |
| 18 | CB 442 | PD | 2,963 | CB 422 | PD | 1,446 | SW 85_PG | PD | 3,789 | SW PG2 | PD | 2,807 |
| 19 | CB72+2CT | PD | 1,785 | CB 442 | PD | 1,446 | SW PG1 | PD | 3,789 | SW 85_PG | PD | 2,807 |
| 20 | CB62+2CT | PD | 1,785 | CB72+2CT | PD | 871 | SW 75_PG | PD | 3,789 | SW 75_PG | PD | 2,807 |
| 21 | CB12+2CT | PD | 1,785 | CB62+2CT | PD | 871 | SW 31 | PD | 3,789 | SW 31 | PD | 2,807 |
| 22 | CB32+2CT | PD | 1,785 | CB12+2CT | PD | 871 | SW 33 | PD | 3,789 | SW 33 | PD | 2,807 |
| 23 | CB42+2CT | PD | 1,785 | CB32+2CT | PD | 871 | SW 41 | PD | 3,789 | SW 41 | PD | 2,807 |
| 24 | CB52+2CT | PD | 1,472 | CB42+2CT | PD | 871 | SW 51 | PD | 3,789 | SW 51 | PD | 2,807 |
| 25 | CB22+2CT | PD | 1,472 | CB52+2CT | PD | 719 | SW 77 | PD | 3,789 | SW 77 | PD | 2,807 |
| 26 | SW62 | PD | 638 | CB22+2CT | PD | 719 | SW 21 | PD | 3,789 | SW 21 | PD | 2,807 |
| 27 | CCPD 442_O | Bus | 423 | SW62 | PD | 473 | SW 27 WP Tap | PD | 3,789 | SW 27 WP Tap | PD | 2,807 |
| 28 | CCPD 422_O | Bus | 423 | SWPG22 | PD | 289 | SW 25 PG Tap | PD | 3,789 | SW 25 PG Tap | PD | 2,807 |
| 29 | CBPG3 | PD | 417 | SWPG42 | PD | 289 | SW 29 | PD | 3,789 | SW 29 | PD | 2,807 |
| 30 | CBPG1 | PD | 417 | CCPD 442_O | Bus | 207 | SW 47 | PD | 3,789 | SW 47 | PD | 2,807 |
| 31 | CB28 | PD | 417 | CCPD 422_O | Bus | 207 | SW 49 | PD | 3,789 | SW 49 | PD | 2,807 |
| 32 | SWPG31 | PD | 406 | CBPG4 | PD | 204 | SW 27 | PD | 3,789 | SW 27 | PD | 2,807 |
| 33 | SWPG11 | PD | 406 | CBPG2 | PD | 204 | CB 422 | PD | 2,963 | LTC PG2 | PD | 2,115 |
| 34 | LTC_VS | Bus | 202 | CB28 | PD | 204 | CB 442 | PD | 2,963 | CB 422 | PD | 1,446 |
| 35 | SW 421 | PD | 141 | SW 421 | PD | 106 | CB72+2CT | PD | 1,785 | CB 442 | PD | 1,446 |
| 36 | SW 441 | PD | 141 | SW 441 | PD | 106 | CB62+2CT | PD | 1,785 | PT 32 | Bus | 980 |
| 37 | CTPG31 | Bus | 25 | LTC_VS | Bus | 99 | CB12+2CT | PD | 1,785 | CB72+2CT | PD | 871 |
| 38 | CTPG11 | Bus | 25 | CTPG42 | Bus | 12 | CB42+2CT | PD | 1,785 | CB62+2CT | PD | 871 |
| 39 | | | 254,166 | CTPG22 | Bus | 12 | PT 32 | Bus | 1,475 | CB12+2CT | PD | 871 |
| | | | | | | 191,864 | CB52+2CT | PD | 1,472 | CB42+2CT | PD | 871 |
| | | | | | | | CB22+2CT | PD | 1,472 | SACT_PG2 | Bus | 803 |
| | | | | | | | CB 12_WP | PD | 1,300 | CB52+2CT | PD | 719 |

# Alternative 1 – VS System ECOST

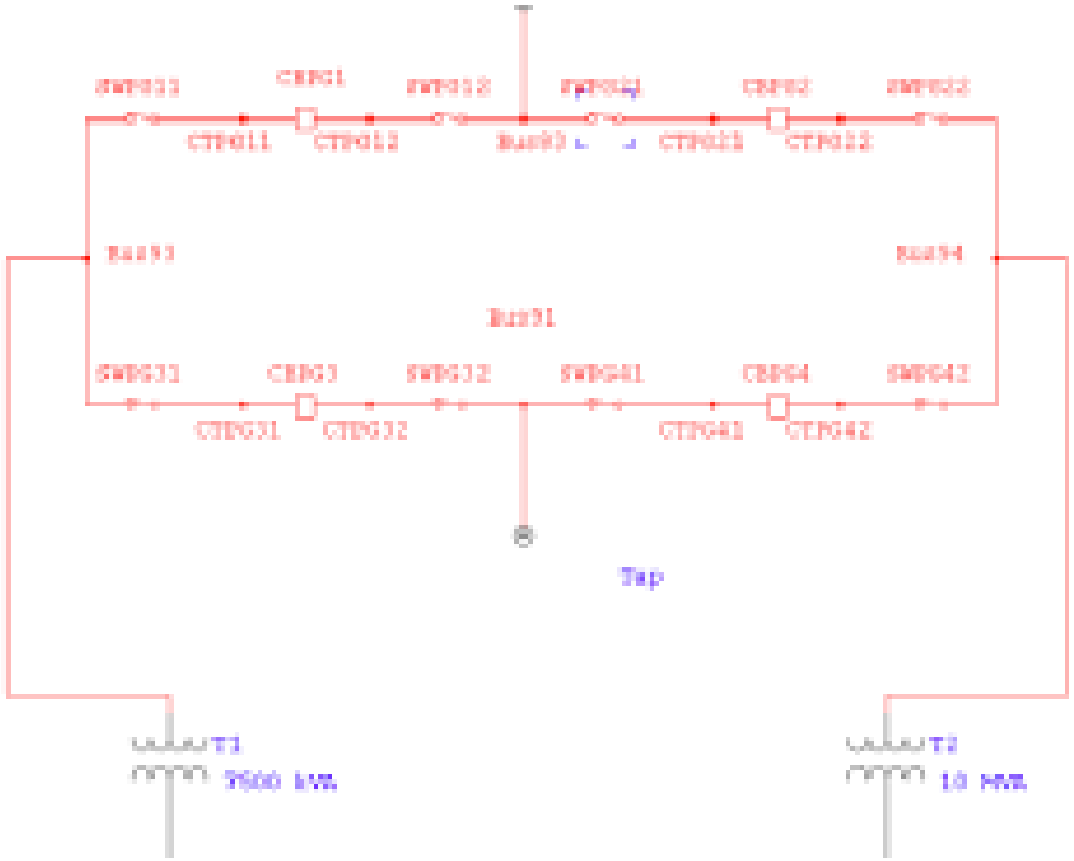
| | With New OHL from VS to PG | | | Without New OHL from VS to PG | | |
|---|---|---|---|---|---|---|
| | Contributing Element | | ECOST | Contributing Element | | ECOST |
| No | ID | Type | $ / yr | ID | Type | $ / yr |
| | System | | 3,851,445 | System | | 3,929,803 |
| 1 | T1_VS | Xfmr2 | 678,972 | T1_VS | Xfmr2 | 678,972 |
| 2 | Line VS_PG_New | Line | 561,098 | Main Bus+2A+2CT VS | Bus | 496,184 |
| 3 | Main Bus+2A+2CT VS | Bus | 496,184 | Line VS_EL | Line | 406,235 |
| 4 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 230,800 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 230,800 |
| 5 | T2_VS | Xfmr2 | 217,714 | T2_VS | Xfmr2 | 217,714 |
| 6 | T1 MRT | Xfmr2 | 70,712 | Line EL_PG JCT | Line | 143,847 |
| 7 | Line EL_PG JCT | Line | 66,196 | CB32+2CT | PD | 78,164 |
| 8 | T1 CL | Xfmr2 | 51,018 | T1 MRT | Xfmr2 | 70,712 |
| 9 | Line PG Tap | Line | 47,619 | Line PG Tap | Line | 61,442 |
| 10 | Bus VS MAIN | Bus | 44,358 | Line PG Jct_WP | Line | 60,652 |
| 11 | Line PG Jct_WP | Line | 40,886 | T1 CL | Xfmr2 | 51,018 |
| 12 | T1 MRM | Xfmr2 | 39,800 | Bus VS MAIN | Bus | 44,358 |
| 13 | T1_EL | Xfmr2 | 39,381 | T1 MRM | Xfmr2 | 39,800 |
| 14 | T1 IN | Xfmr2 | 38,382 | T1_EL | Xfmr2 | 39,381 |
| 15 | SW 77 | PD | 38,299 | T1 IN | Xfmr2 | 38,382 |
| 16 | SW 51 | PD | 38,299 | SW 71 | PD | 38,299 |
| 17 | SW 21 | PD | 38,299 | SW 73 | PD | 38,299 |
| 18 | SW 73 | PD | 38,299 | SW 61 | PD | 38,299 |
| 19 | SW 71 | PD | 38,299 | SW 11 | PD | 38,299 |
| 20 | SW 41 | PD | 38,299 | SW 31 | PD | 38,299 |
| 21 | SW 61 | PD | 38,299 | SW 41 | PD | 38,299 |
| 22 | SW 11 | PD | 38,299 | SW 51 | PD | 38,299 |
| 23 | SW 31 | PD | 38,299 | SW 77 | PD | 38,299 |
| 24 | T1 PG | Xfmr2 | 36,105 | SW 21 | PD | 38,299 |
| 25 | CB42+2CT | PD | 33,283 | T1 PG | Xfmr2 | 36,105 |
| 26 | CB52+2CT | PD | 31,384 | CB42+2CT | PD | 33,283 |
| 27 | Line IN Tab_IN Sub | Line | 29,502 | CB52+2CT | PD | 31,384 |
| 28 | T2 PG | Xfmr2 | 28,310 | Line IN Tab_IN Sub | Line | 29,502 |
| 29 | T1 CC | Xfmr2 | 27,719 | T2 PG | Xfmr2 | 28,310 |
| 30 | Line VS_PRD Sw's | Line | 27,291 | T1 CC | Xfmr2 | 27,719 |

# Alternative 2 – New MRT – PG OHL



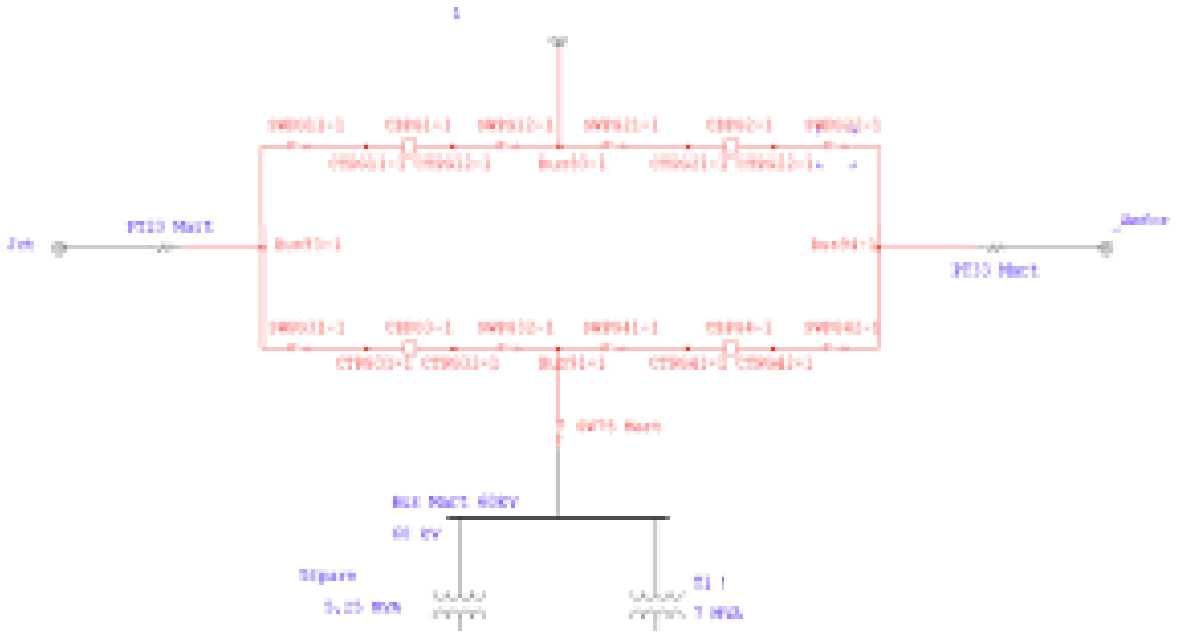
New 10 mile 60 kV OHL from MRT Sub to PG Sub

# Alternative 2 – Upgraded PG Substation




PG 60 kV Switchyard Rebuilt to Ring Bus

# Alternative 2 – Upgraded MRT Substation



MRT 60kV Switchyard Rebuilt to Ring Bus

# Alternative 2 – Reliability Results

| | | W/ New OHL MRL-PG | | W/o New OHL MRL-PG | |
|---|---|---|---|---|---|
| Bus/Load | Load Sector | Average Interrupting Rate | Annual Outage Duration | Average Interrupting Rate | Annual Outage Duration |
| ID | | f / yr | hr / yr | f / yr | hr / yr |
| Bus PG1101 | N/A | 0.5867 | 7.34 | 1.7447 | 16.43 |
| Bus PG1102 | N/A | 0.5900 | 7.42 | 1.7494 | 16.52 |
| Bus WP1101 | N/A | 1.7466 | 10.73 | 1.7508 | 16.18 |
| Bus WP1103 | N/A | 1.7452 | 10.73 | 1.7494 | 16.18 |
| Bus EL1101 | N/A | 1.7452 | 10.12 | 1.7494 | 13.85 |
| Bus EL1102 | N/A | 1.7452 | 10.12 | 1.7494 | 13.85 |

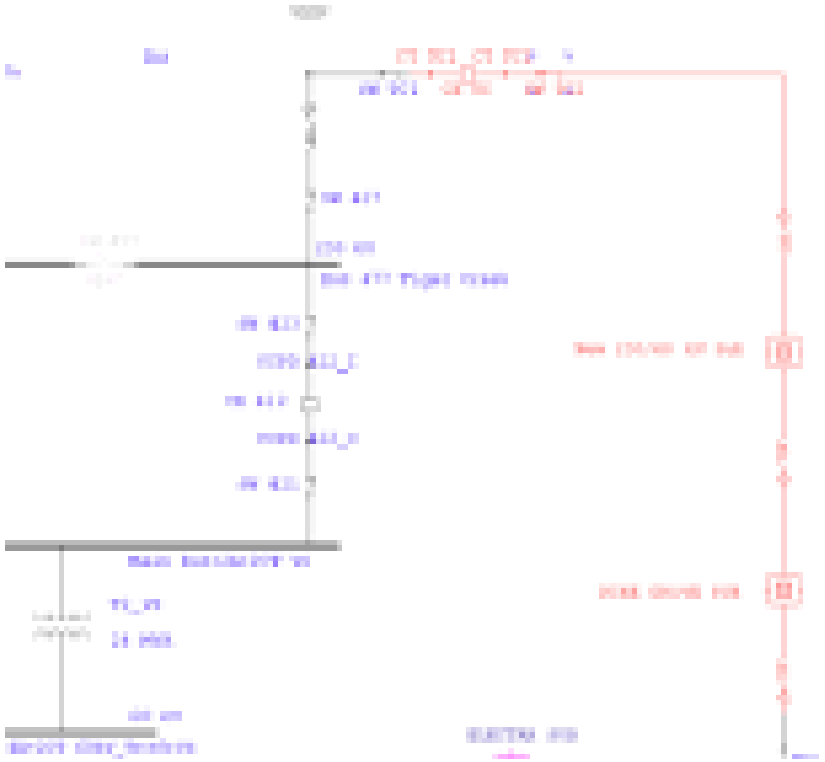
# Alternative 2 – PG 12 kV buses ECOST

| | With New OHL from MRT to PG | | | | | | Without New OHL from MRT to PG | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Contributing Element | | ECOST | Contributing Element | | ECOST | Contributing Element | | ECOST | Contributing Element | | ECOST |
| No | ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr |
| 1 | **Bus PG1101** | | **253,110** | **Bus PG1102** | | 191,188 | **Bus PG1101** | | **546,381** | **Bus PG1102** | | **400,433** |
| 2 | T1_VS | Xfmr2 | 65,505 | T1_VS | Xfmr2 | 51,363 | Line VS_EL | Line | 124,966 | Line VS_EL | Line | 89,736 |
| 3 | Main Bus+2A+2CT VS | Bus | 48,472 | Main Bus+2A+2CT VS | Bus | 36,959 | T1_VS | Xfmr2 | 65,505 | T1_VS | Xfmr2 | 51,363 |
| 4 | T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 | Line EL_PG JCT | Line | 59,836 | Line EL_PG JCT | Line | 42,967 |
| 5 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 22,547 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 17,192 | Main Bus+2A+2CT VS | Bus | 48,472 | Main Bus+2A+2CT VS | Bus | 36,959 |
| 6 | T2_VS | Xfmr2 | 21,205 | T2_VS | Xfmr2 | 16,278 | T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 |
| 7 | Bus VS MAIN | Bus | 4,353 | Bus VS MAIN | Bus | 3,285 | Line PG Tap | Line | 31,069 | Line PG Tap | Line | 22,310 |
| 8 | SW 51 | PD | 3,789 | SW 51 | PD | 2,807 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 22,547 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 17,192 |
| 9 | SW 31 | PD | 3,789 | SW 31 | PD | 2,807 | T2_VS | Xfmr2 | 21,205 | T2_VS | Xfmr2 | 16,278 |
| 10 | SW 73 | PD | 3,789 | SW 73 | PD | 2,807 | CB32+2CT | PD | 20,065 | CB32+2CT | PD | 15,299 |
| 11 | SW 21 | PD | 3,789 | SW 21 | PD | 2,807 | Line PG Jct_WP | Line | 13,282 | Line PG Jct_WP | Line | 6,483 |
| 12 | SW 71 | PD | 3,789 | SW 71 | PD | 2,807 | Bus VS MAIN | Bus | 4,353 | Bus VS MAIN | Bus | 3,285 |
| 13 | SW 77 | PD | 3,789 | SW 77 | PD | 2,807 | SW 71 | PD | 3,789 | SW 71 | PD | 2,807 |
| 14 | SW 41 | PD | 3,789 | SW 41 | PD | 2,807 | SW 73 | PD | 3,789 | SW 73 | PD | 2,807 |
| 15 | SW 61 | PD | 3,789 | SW 61 | PD | 2,807 | SW 61 | PD | 3,789 | SW 61 | PD | 2,807 |
| 16 | SW 11 | PD | 3,789 | SW 11 | PD | 2,807 | SW 11 | PD | 3,789 | SW 11 | PD | 2,807 |
| 17 | CB 422 | PD | 2,963 | LTC PG2 | PD | 2,115 | SW 45_E | PD | 3,789 | SW 45_E | PD | 2,807 |
| 18 | CB 442 | PD | 2,963 | CB 422 | PD | 1,446 | SW 85_PG | PD | 3,789 | SW PG2 | PD | 2,807 |
| 19 | CB32+2CT | PD | 1,785 | CB 442 | PD | 1,446 | SW PG1 | PD | 3,789 | SW 85_PG | PD | 2,807 |
| 20 | CB72+2CT | PD | 1,785 | CB32+2CT | PD | 871 | SW 75_PG | PD | 3,789 | SW 75_PG | PD | 2,807 |
| 21 | CB42+2CT | PD | 1,785 | CB72+2CT | PD | 871 | SW 31 | PD | 3,789 | SW 31 | PD | 2,807 |
| 22 | CB62+2CT | PD | 1,785 | CB42+2CT | PD | 871 | SW 33 | PD | 3,789 | SW 33 | PD | 2,807 |
| 23 | CB12+2CT | PD | 1,785 | CB62+2CT | PD | 871 | SW 41 | PD | 3,789 | SW 41 | PD | 2,807 |
| 24 | CB52+2CT | PD | 1,472 | CB12+2CT | PD | 871 | SW 51 | PD | 3,789 | SW 51 | PD | 2,807 |
| 25 | CB22+2CT | PD | 1,472 | CB52+2CT | PD | 719 | SW 77 | PD | 3,789 | SW 77 | PD | 2,807 |
| 26 | CCPD 442_O | Bus | 423 | CB22+2CT | PD | 719 | SW 21 | PD | 3,789 | SW 21 | PD | 2,807 |
| 27 | CCPD 422_O | Bus | 423 | SWPG42 | PD | 289 | SW 27 WP Tap | PD | 3,789 | SW 27 WP Tap | PD | 2,807 |
| 28 | CBPG1 | PD | 417 | SWPG22 | PD | 289 | SW 25 PG Tap | PD | 3,789 | SW 25 PG Tap | PD | 2,807 |
| 29 | CBPG3 | PD | 417 | CCPD 442_O | Bus | 207 | SW 29 | PD | 3,789 | SW 29 | PD | 2,807 |
| 30 | SWPG11 | PD | 406 | CCPD 422_O | Bus | 207 | SW 47 | PD | 3,789 | SW 47 | PD | 2,807 |
| 31 | SWPG31 | PD | 406 | CBPG2 | PD | 204 | SW 49 | PD | 3,789 | SW 49 | PD | 2,807 |

# Alternative 2 – VS System ECOST

| | With New OHL from MRT to PG | | | Without New OHL from MRT to PG | | |
|---|---|---|---|---|---|---|
| | Contributing Element | | ECOST | Contributing Element | | ECOST |
| No | ID | Type | $ / yr | ID | Type | $ / yr |
| | System | | 3,629,745 | System | | 3,929,803 |
| 1 | T1_VS | Xfmr2 | 678,972 | T1_VS | Xfmr2 | 678,972 |
| 2 | Main Bus+2A+2CT VS | Bus | 496,184 | Main Bus+2A+2CT VS | Bus | 496,184 |
| 3 | Line MRT_PG | Line | 374,065 | Line VS_EL | Line | 406,235 |
| 4 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 230,800 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 230,800 |
| 5 | T2_VS | Xfmr2 | 217,714 | T2_VS | Xfmr2 | 217,714 |
| 6 | T1 MRT | Xfmr2 | 70,712 | Line EL_PG JCT | Line | 143,847 |
| 7 | Line EL_PG JCT | Line | 66,196 | CB32+2CT | PD | 78,164 |
| 8 | T1 CL | Xfmr2 | 51,018 | T1 MRT | Xfmr2 | 70,712 |
| 9 | Line PG Tap | Line | 47,619 | Line PG Tap | Line | 61,442 |
| 10 | Bus VS MAIN | Bus | 44,358 | Line PG Jct_WP | Line | 60,652 |
| 11 | Line PG Jct_WP | Line | 40,886 | T1 CL | Xfmr2 | 51,018 |
| 12 | T1 MRM | Xfmr2 | 39,800 | Bus VS MAIN | Bus | 44,358 |
| 13 | T1_EL | Xfmr2 | 39,381 | T1 MRM | Xfmr2 | 39,800 |
| 14 | T1 IN | Xfmr2 | 38,382 | T1_EL | Xfmr2 | 39,381 |
| 15 | SW 51 | PD | 38,299 | T1 IN | Xfmr2 | 38,382 |
| 16 | SW 77 | PD | 38,299 | SW 71 | PD | 38,299 |
| 17 | SW 73 | PD | 38,299 | SW 73 | PD | 38,299 |
| 18 | SW 71 | PD | 38,299 | SW 61 | PD | 38,299 |
| 19 | SW 41 | PD | 38,299 | SW 11 | PD | 38,299 |
| 20 | SW 21 | PD | 38,299 | SW 31 | PD | 38,299 |
| 21 | SW 11 | PD | 38,299 | SW 41 | PD | 38,299 |
| 22 | SW 61 | PD | 38,299 | SW 51 | PD | 38,299 |
| 23 | SW 31 | PD | 38,299 | SW 77 | PD | 38,299 |
| 24 | T1 PG | Xfmr2 | 36,105 | SW 21 | PD | 38,299 |
| 25 | CB42+2CT | PD | 33,283 | T1 PG | Xfmr2 | 36,105 |
| 26 | CB52+2CT | PD | 31,384 | CB42+2CT | PD | 33,283 |
| 27 | Line IN Tab_IN Sub | Line | 29,502 | CB52+2CT | PD | 31,384 |
| 28 | T2 PG | Xfmr2 | 28,310 | Line IN Tab_IN Sub | Line | 29,502 |
| 29 | T1 CC | Xfmr2 | 27,719 | T2 PG | Xfmr2 | 28,310 |
| 30 | Line VS_PRD Sw's | Line | 27,291 | T1 CC | Xfmr2 | 27,719 |

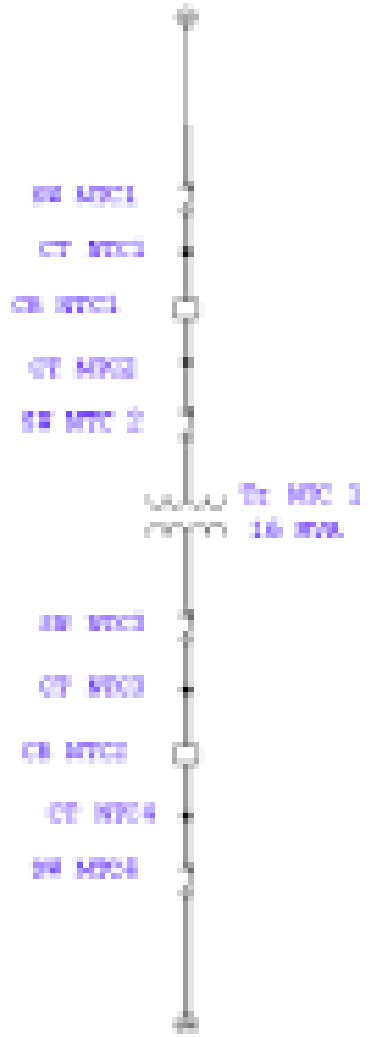
# Alternative 3



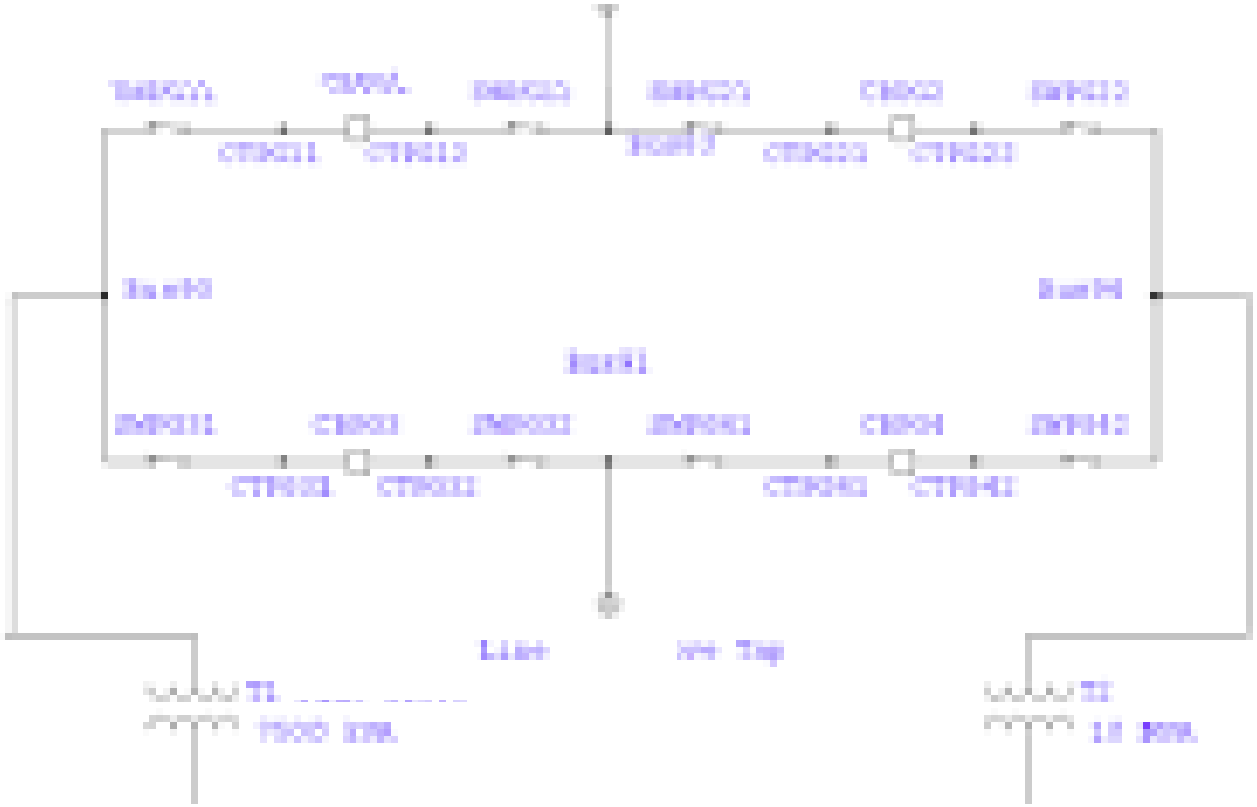
New 8.8 mile 230 kV OHL from TC Sub to PG Jct. with new PG 230/60 kV Sub

New 2.7 mile 60 kV OHL from PG Jct. to PG Sub

# Alternative 3 – New PG Junction 230/60kV Sub



# Alternative 3



PG 60 kV Switchyard Rebuilt to a Ring Bus

# Alternative 3 – Reliability Results

| Bus/Load | Load Sector | W/ New Sub from TC | | W/o New Sub from TC | |
|---|---|---|---|---|---|
| | | Average Interrupting Rate | Annual Outage Duration | Average Interrupting Rate | Annual Outage Duration |
| ID | | f / yr | hr / yr | f / yr | hr / yr |
| Bus PG1101 | N/A | 0.0799 | 1.16 | 1.7447 | 16.43 |
| Bus PG1102 | N/A | 0.0832 | 1.24 | 1.7494 | 16.52 |
| Bus WP1101 | N/A | 1.2689 | 4.61 | 1.7508 | 16.18 |
| Bus WP1103 | N/A | 1.2675 | 4.61 | 1.7494 | 16.18 |
| Bus EL1101 | N/A | 1.2675 | 3.99 | 1.7494 | 13.85 |
| Bus EL1102 | N/A | 1.2675 | 3.99 | 1.7494 | 13.85 |

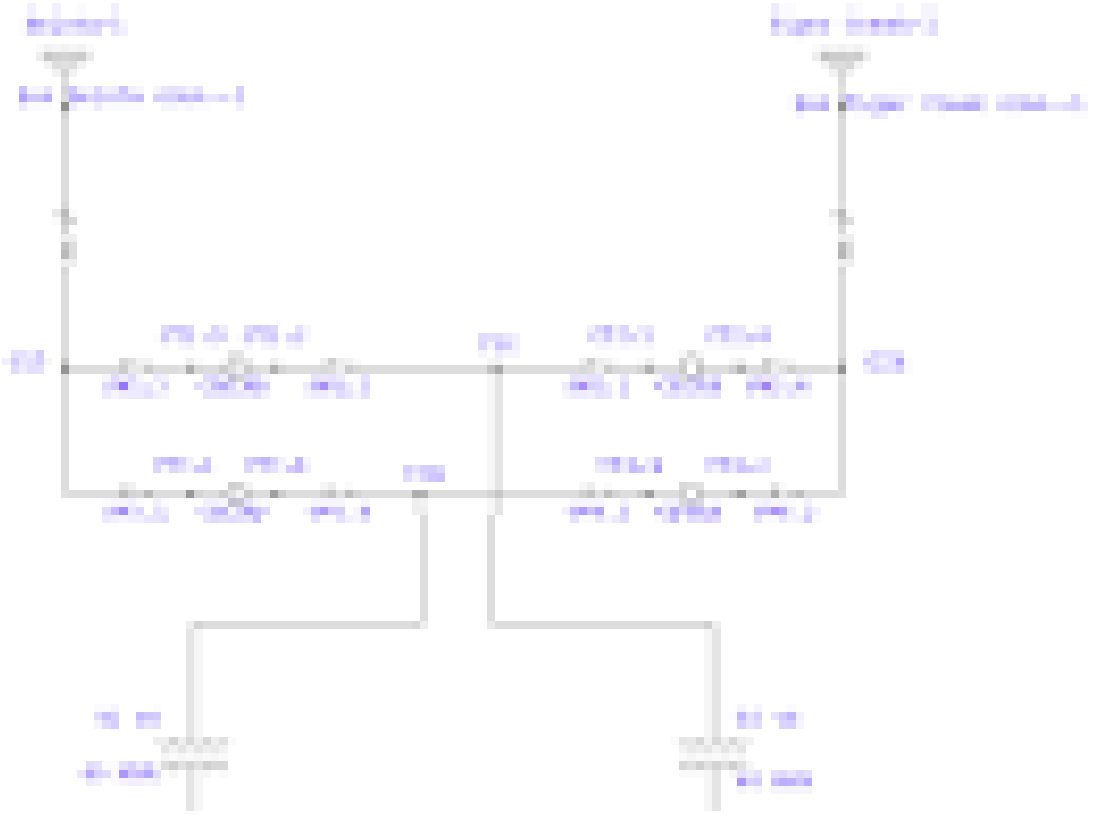
# Alternative 3 – PG 12 kV buses ECOST

| | With New OHL from MRT to PG | | | | | | Without New OHL from MRT to PG | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Contributing Element | | ECOST | Contributing | | ECOST | Contributing Element | | ECOST | Contributing Element | | ECOST |
| No | ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr |
| 1 | **Bus PG1101** | | **40,763** | **Bus PG1102** | | **32,880** | **Bus PG1101** | | **546,381** | **Bus PG1102** | | **400,433** |
| 2 | T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 | Line VS_EL | Line | 124,966 | Line VS_EL | Line | 89,736 |
| 3 | CB 422 | PD | 2,963 | LTC PG2 | PD | 2,115 | T1_VS | Xfmr2 | 65,505 | T1_VS | Xfmr2 | 51,363 |
| 4 | CBPG3 | PD | 417 | CB 422 | PD | 1,446 | Line EL_PG JCT | Line | 59,836 | Line EL_PG JCT | Line | 42,967 |
| 5 | CBPG1 | PD | 417 | SWPG42 | PD | 289 | Main Bus+2A+2CT VS | Bus | 48,472 | Main Bus+2A+2CT VS | Bus | 36,959 |
| 6 | SWPG11 | PD | 406 | SWPG22 | PD | 289 | T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 |
| 7 | SWPG31 | PD | 406 | CBPG4 | PD | 204 | Line PG Tap | Line | 31,069 | Line PG Tap | Line | 22,310 |
| 8 | CTPG31 | Bus | 25 | CBPG2 | PD | 204 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 22,547 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 17,192 |
| 9 | CTPG11 | Bus | 25 | CTPG42 | Bus | 12 | T2_VS | Xfmr2 | 21,205 | T2_VS | Xfmr2 | 16,278 |
| 10 | | | **40,763** | CTPG22 | Bus | 12 | CB32+2CT | PD | 20,065 | CB32+2CT | PD | 15,299 |
| | | | | | | **32,880** | Line PG Jct_WP | Line | 13,282 | Line PG Jct_WP | Line | 6,483 |
| | | | | | | | Bus VS MAIN | Bus | 4,353 | Bus VS MAIN | Bus | 3,285 |
| | | | | | | | SW 71 | PD | 3,789 | SW 71 | PD | 2,807 |
| | | | | | | | SW 73 | PD | 3,789 | SW 73 | PD | 2,807 |
| | | | | | | | SW 61 | PD | 3,789 | SW 61 | PD | 2,807 |
| | | | | | | | SW 11 | PD | 3,789 | SW 11 | PD | 2,807 |
| | | | | | | | SW 45_E | PD | 3,789 | SW 45_E | PD | 2,807 |
| | | | | | | | SW 85_PG | PD | 3,789 | SW PG2 | PD | 2,807 |
| | | | | | | | SW PG1 | PD | 3,789 | SW 85_PG | PD | 2,807 |
| | | | | | | | SW 75_PG | PD | 3,789 | SW 75_PG | PD | 2,807 |
| | | | | | | | SW 31 | PD | 3,789 | SW 31 | PD | 2,807 |
| | | | | | | | SW 33 | PD | 3,789 | SW 33 | PD | 2,807 |
| | | | | | | | SW 41 | PD | 3,789 | SW 41 | PD | 2,807 |
| | | | | | | | SW 51 | PD | 3,789 | SW 51 | PD | 2,807 |
| | | | | | | | SW 77 | PD | 3,789 | SW 77 | PD | 2,807 |
| | | | | | | | SW 21 | PD | 3,789 | SW 21 | PD | 2,807 |
| | | | | | | | SW 27 WP Tap | PD | 3,789 | SW 27 WP Tap | PD | 2,807 |
| | | | | | | | SW 25 PG Tap | PD | 3,789 | SW 25 PG Tap | PD | 2,807 |
| | | | | | | | SW 29 | PD | 3,789 | SW 29 | PD | 2,807 |
| | | | | | | | SW 47 | PD | 3,789 | SW 47 | PD | 2,807 |
| | | | | | | | SW 49 | PD | 3,789 | SW 49 | PD | 2,807 |

# Alternative 3 – VS System ECOST

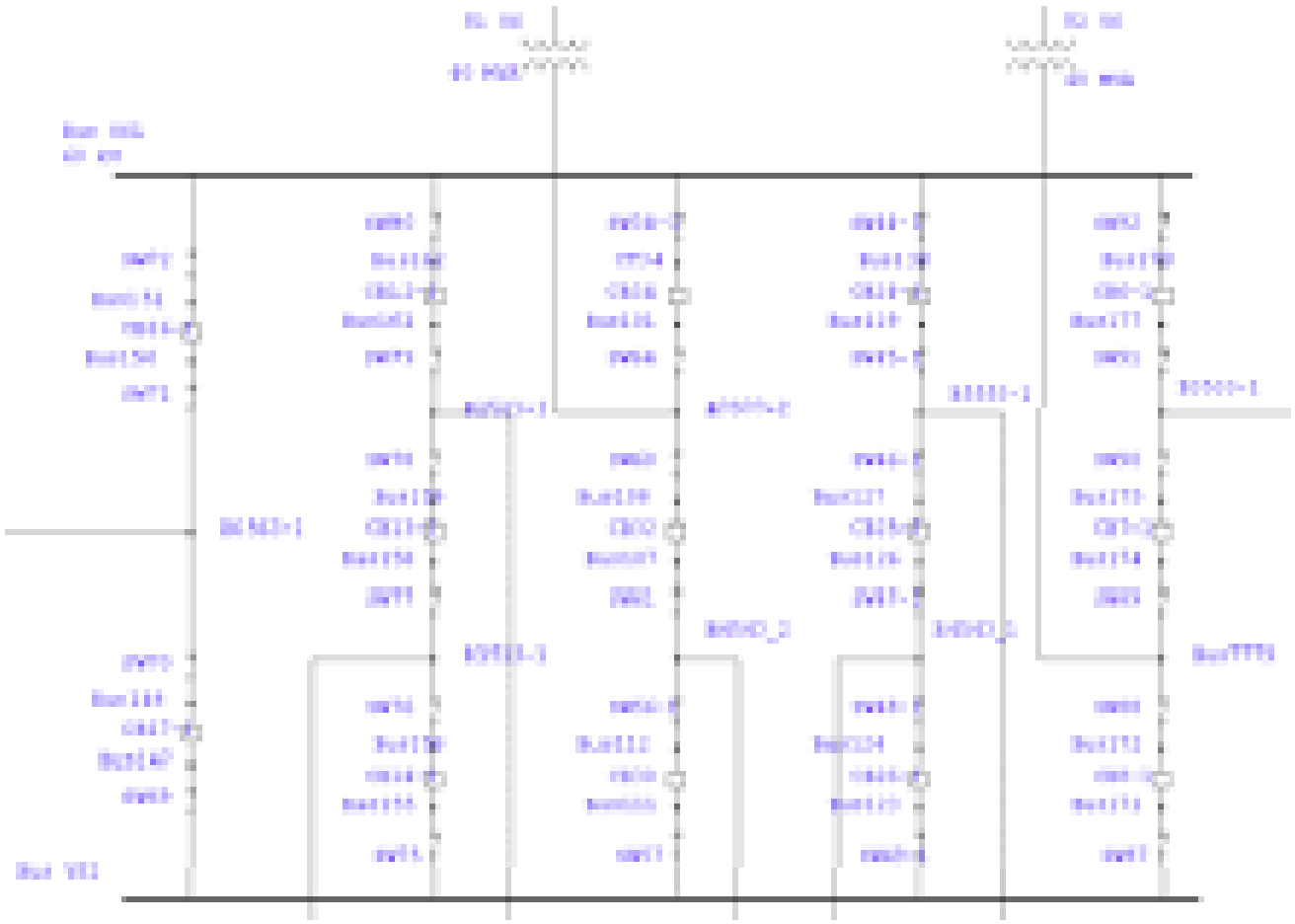
| | With New Sub from TC | | | Without New Sub from TC | | |
|---|---|---|---|---|---|---|
| | Contributing Element | | ECOST | Contributing Element | | ECOST |
| No | ID | Type | $ / yr | ID | Type | $ / yr |
| | System | | 3,278,223 | System | | 3,929,803 |
| 1 | T1_VS | Xfmr2 | 454,863 | T1_VS | Xfmr2 | 678,972 |
| 2 | Tr NTC 1 | Xfmr2 | 382,044 | Main Bus+2A+2CT VS | Bus | 496,184 |
| 3 | Main Bus+2A+2CT VS | Bus | 333,054 | Line VS_EL | Line | 406,235 |
| 4 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 154,920 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 230,800 |
| 5 | T2_VS | Xfmr2 | 146,068 | T2_VS | Xfmr2 | 217,714 |
| 6 | Line TC | Line | 107,535 | Line EL_PG JCT | Line | 143,847 |
| 7 | Line NewSub_PG | Line | 100,998 | CB32+2CT | PD | 78,164 |
| 8 | T1 MRT | Xfmr2 | 70,712 | T1 MRT | Xfmr2 | 70,712 |
| 9 | Line EL_PG JCT | Line | 66,196 | Line PG Tap | Line | 61,442 |
| 10 | T1 CL | Xfmr2 | 51,018 | Line PG Jct_WP | Line | 60,652 |
| 11 | Line PG Tap | Line | 47,619 | T1 CL | Xfmr2 | 51,018 |
| 12 | Line PG Jct_WP | Line | 40,886 | Bus VS MAIN | Bus | 44,358 |
| 13 | TC | Syn. Gen | 40,644 | T1 MRM | Xfmr2 | 39,800 |
| 14 | T1 MRM | Xfmr2 | 39,800 | T1_EL | Xfmr2 | 39,381 |
| 15 | T1_EL | Xfmr2 | 39,381 | T1 IN | Xfmr2 | 38,382 |
| 16 | Line TC_PG | Line | 39,298 | SW 71 | PD | 38,299 |
| 17 | T1 IN | Xfmr2 | 38,382 | SW 73 | PD | 38,299 |
| 18 | T1 PG | Xfmr2 | 36,105 | SW 61 | PD | 38,299 |
| 19 | Bus VS MAIN | Bus | 29,796 | SW 11 | PD | 38,299 |
| 20 | Line IN Tab_IN Sub | Line | 29,502 | SW 31 | PD | 38,299 |
| 21 | CB42+2CT | PD | 28,547 | SW 41 | PD | 38,299 |
| 22 | T2 PG | Xfmr2 | 28,310 | SW 51 | PD | 38,299 |
| 23 | T1 CC | Xfmr2 | 27,719 | SW 77 | PD | 38,299 |
| 24 | CB52+2CT | PD | 27,479 | SW 21 | PD | 38,299 |
| 25 | Line VS_PRD Sw's | Line | 27,291 | T1 PG | Xfmr2 | 36,105 |
| 26 | SW 61 | PD | 25,758 | CB42+2CT | PD | 33,283 |
| 27 | SW 11 | PD | 25,758 | CB52+2CT | PD | 31,384 |
| 28 | SW 73 | PD | 25,758 | Line IN Tab_IN Sub | Line | 29,502 |
| 29 | SW 71 | PD | 25,758 | T2 PG | Xfmr2 | 28,310 |
| 30 | SW 31 | PD | 25,758 | T1 CC | Xfmr2 | 27,719 |

# Alternative 4 – Upgraded VS Substation



230kV Upgraded from Collector Bus to Ring Bus

# Alternative 4 – Upgraded VS Substation



60kV Upgraded from MTB to BAAH

# Alternative 4 – Reliability Results

- Reliability Results for Buses & Loads in PG Sub

| Bus/Load | Load Sector | Before | | After | |
|---|---|---|---|---|---|
| | | Average Interrupting Rate | Annual Outage Duration | Average Interrupting Rate | Annual Outage Duration |
| ID | | f / yr | hr / yr | f / yr | hr / yr |
| Bus PG1101 | N/A | 1.7447 | 16.43 | 1.2360 | 9.86 |
| Bus PG1102 | N/A | 1.7494 | 16.52 | 1.2407 | 9.95 |
| L1101_Res_PG | Residential | 1.7447 | 16.43 | 1.2360 | 9.86 |
| L1101_Com_PG | Commercial | 1.7447 | 16.43 | 1.2360 | 9.86 |
| L1101_Ind_PG | Industrial | 1.7447 | 16.43 | 1.2360 | 9.86 |
| L1101_Agr_PG | Agricultural | 1.7447 | 16.43 | 1.2360 | 9.86 |
| L1102_Res_PG | Residential | 1.7494 | 16.52 | 1.2407 | 9.95 |
| L1102_Com_PG | Commercial | 1.7494 | 16.52 | 1.2407 | 9.95 |
| L1102_Ind_PG | Industrial | 1.7494 | 16.52 | 1.2407 | 9.95 |
| L1102_Agr_PG | Agricultural | 1.7494 | 16.52 | 1.2407 | 9.95 |

# Alternative 4 – Reliability Results

| Substation | Loads/Feeders | Bank/ Txf # | Original VS Sub | | Updated VS Sub | |
|---|---|---|---|---|---|---|
| | | | Average Interrupting | Annual Outage Duration | Average Interrupting | Annual Outage Duration |
| | | | f / yr | hr/yr | f / yr | hr/yr |
| CC | CC 1101 | Bk 1 | 0.8529 | 9.24 | 0.3442 | 2.76 |
| CL | CL 1101 | Bk 1 | 1.3642 | 9.28 | 0.8555 | 3.10 |
| | CL 1102 | Bk 1 | 1.3642 | 9.28 | 0.8555 | 3.10 |
| | CL 1103 | Bk 2 | 1.3401 | 9.27 | 0.8314 | 3.09 |
| CRL | CRL 1101 | Bk 1 | 0.6625 | 8.51 | 0.1538 | 1.94 |
| | CRL 1102 | Bk 2 | 0.6961 | 8.86 | 0.1874 | 2.29 |
| | CRL 1103 | Bk 1 | 0.6625 | 8.51 | 0.1538 | 1.94 |
| EL | EL 1101 | Bk 1 | 1.7494 | 13.85 | 1.2407 | 7.28 |
| | EL 1102 | Bk 1 | 1.7494 | 13.85 | 1.2407 | 7.28 |
| IN | IN 1101 | Bk 2 | 1.3401 | 9.80 | 0.8314 | 3.62 |
| LND | LND 1101 | Bk 1 | 0.1678 | 2.15 | 0.1678 | 2.15 |
| | LND 1102 | Bk 1 | 0.1678 | 2.15 | 0.1678 | 2.15 |
| | LND 1103 | Bk 1 | 0.1678 | 2.15 | 0.1678 | 2.15 |
| | LND 1104 | Bk 1 | 0.1678 | 2.15 | 0.1678 | 2.15 |
| MRT | MRT 1101 | Bk 1 | 0.6857 | 8.36 | 0.1306 | 2.09 |
| | MRT 1102 | Bk 1 | 0.6857 | 8.36 | 0.1306 | 2.09 |
| | MRT 1103 | Bk 1 | 0.6857 | 8.36 | 0.1306 | 2.09 |
| MRM | MRM 1101 | Bk 1 | 0.1349 | 1.67 | 0.1349 | 1.67 |
| | MRM 1102 | Bk 1 | 0.1349 | 1.67 | 0.1349 | 1.67 |
| NB | NB 1101 | Bk 1 | 0.8461 | 8.92 | 0.3374 | 2.45 |
| OL | OL 1101 | Bk 1 | 0.0528 | 1.41 | 0.0528 | 1.41 |
| | OL 1102 | Bk 2 | 0.0817 | 1.48 | 0.0817 | 1.48 |
| PG | PG 1101 | Bk 1 | 1.7447 | 16.43 | 1.2360 | 9.86 |
| | PG 1102 | Bk 2 | 1.7494 | 16.52 | 1.2407 | 9.95 |
| WP | WP 1101 | Bk 2 | 1.7508 | 16.18 | 1.2421 | 9.62 |
| | WP 1102 | Bk 3 | 1.7494 | 16.18 | 1.2407 | 9.61 |

# Alternative 4 – PG 12 kV buses ECOST

| Original VS System | | | | | | VS System with New VS Sub | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Contributing Element | | ECOST | Contributing Element | | ECOST | Contributing Element | | ECOST | Contributing Element | | ECOST |
| ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr | ID | Type | $ / yr |
| **Bus PG1101** | | **546,381** | **Bus PG1102** | | **400,433** | **Bus PG1101** | | **320,639** | **Bus PG1102** | | **231,619** |
| Line VS_EL | Line | 124,966 | Line VS_EL | Line | 89,736 | Line VS_EL | Line | 124,966 | Line VS_EL | Line | 89,736 |
| T1_VS | Xfmr2 | 65,505 | T1_VS | Xfmr2 | 51,363 | Line EL_PG JCT | Line | 59,836 | Line EL_PG JCT | Line | 42,967 |
| Line EL_PG JCT | Line | 59,836 | Line EL_PG JCT | Line | 42,967 | T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 |
| Main Bus+2A+2CT VS | Bus | 48,472 | Main Bus+2A+2CT VS | Bus | 36,959 | Line PG Tap | Line | 31,069 | Line PG Tap | Line | 22,310 |
| T1 PG | Xfmr2 | 36,105 | T2 PG | Xfmr2 | 28,310 | Line PG Jct_WP | Line | 13,282 | Line PG Jct_WP | Line | 6,483 |
| Line PG Tap | Line | 31,069 | Line PG Tap | Line | 22,310 | SW91 | PD | 5,170 | SW91 | PD | 3,901 |
| Bus+4A+2CT 60kV_TrsfrVS | Bus | 22,547 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 17,192 | SW90 | PD | 5,170 | SW90 | PD | 3,901 |
| T2_VS | Xfmr2 | 21,205 | T2_VS | Xfmr2 | 16,278 | SW 45_E | PD | 3,789 | SW 45_E | PD | 2,807 |
| CB32+2CT | PD | 20,065 | CB32+2CT | PD | 15,299 | SW 85_PG | PD | 3,789 | SW PG2 | PD | 2,807 |
| Line PG Jct_WP | Line | 13,282 | Line PG Jct_WP | Line | 6,483 | SW PG1 | PD | 3,789 | SW 85_PG | PD | 2,807 |
| Bus VS MAIN | Bus | 4,353 | Bus VS MAIN | Bus | 3,285 | SW 75_PG | PD | 3,789 | SW 75_PG | PD | 2,807 |
| SW 71 | PD | 3,789 | SW 71 | PD | 2,807 | SW 27 WP Tap | PD | 3,789 | SW 27 WP Tap | PD | 2,807 |
| SW 73 | PD | 3,789 | SW 73 | PD | 2,807 | SW 25 PG Tap | PD | 3,789 | SW 25 PG Tap | PD | 2,807 |
| SW 61 | PD | 3,789 | SW 61 | PD | 2,807 | SW 29 | PD | 3,789 | SW 29 | PD | 2,807 |
| SW 11 | PD | 3,789 | SW 11 | PD | 2,807 | SW 47 | PD | 3,789 | SW 47 | PD | 2,807 |
| SW 45_E | PD | 3,789 | SW 45_E | PD | 2,807 | SW 49 | PD | 3,789 | SW 49 | PD | 2,807 |
| SW 85_PG | PD | 3,789 | SW PG2 | PD | 2,807 | SW 27 | PD | 3,789 | SW 27 | PD | 2,807 |
| SW PG1 | PD | 3,789 | SW 85_PG | PD | 2,807 | CB7-1 | PD | 1,300 | LTC PG2 | PD | 2,115 |
| SW 75_PG | PD | 3,789 | SW 75_PG | PD | 2,807 | CB6-1 | PD | 1,300 | SACT_PG2 | Bus | 803 |
| SW 31 | PD | 3,789 | SW 31 | PD | 2,807 | CB 12_WP | PD | 1,300 | CB7-1 | PD | 635 |
| SW 33 | PD | 3,789 | SW 33 | PD | 2,807 | SA_PG1 | Bus | 959 | CB6-1 | PD | 635 |
| SW 41 | PD | 3,789 | SW 41 | PD | 2,807 | SW 13_1_WP | PD | 583 | CB 12_WP | PD | 635 |
| SW 51 | PD | 3,789 | SW 51 | PD | 2,807 | SW 95_WP | PD | 583 | SW 13_1_WP | PD | 284 |
| SW 77 | PD | 3,789 | SW 77 | PD | 2,807 | SW 17 | PD | 583 | SW 95_WP | PD | 284 |
| SW 21 | PD | 3,789 | SW 21 | PD | 2,807 | Fuse 1_E | PD | 86 | SW 17 | PD | 284 |
| SW 27 WP Tap | PD | 3,789 | SW 27 WP Tap | PD | 2,807 | Fuse WP | PD | 86 | Fuse 1_E | PD | 42 |
| SW 25 PG Tap | PD | 3,789 | SW 25 PG Tap | PD | 2,807 | Fuse PG1 | PD | 86 | Fuse WP | PD | 42 |
| SW 29 | PD | 3,789 | SW 29 | PD | 2,807 | CT 12_1_WP | Bus | 86 | Fuse PG1 | PD | 42 |
| SW 47 | PD | 3,789 | SW 47 | PD | 2,807 | Bus177 | Bus | 86 | CT 12_1_WP | Bus | 42 |
| SW 49 | PD | 3,789 | SW 49 | PD | 2,807 | Bus175 | Bus | 86 | Bus177 | Bus | 42 |

# Alternative 4 – VS System ECOST

| | Original VS Sub | | | New VS Sub | | |
|---|---|---|---|---|---|---|
| | Contributing Element | | ECOST | Contributing Element | | ECOST |
| No | ID | Type | $ / yr | ID | Type | $ / yr |
| | System | | 3,929,803 | System | | 1,700,614 |
| 1 | T1_VS | Xfmr2 | 678,972 | Line VS_EL | Line | 406,235 |
| 2 | Main Bus+2A+2CT VS | Bus | 496,184 | Line EL_PG JCT | Line | 143,847 |
| 3 | Line VS_EL | Line | 406,235 | T1 MRT | Xfmr2 | 70,712 |
| 4 | Bus+4A+2CT 60kV_TrsfrVS | Bus | 230,800 | Line PG Tap | Line | 61,442 |
| 5 | T2_VS | Xfmr2 | 217,714 | Line PG Jct_WP | Line | 60,652 |
| 6 | Line EL_PG JCT | Line | 143,847 | T1 CL | Xfmr2 | 51,018 |
| 7 | CB32+2CT | PD | 78,164 | T1 MRM | Xfmr2 | 39,800 |
| 8 | T1 MRT | Xfmr2 | 70,712 | T1_EL | Xfmr2 | 39,381 |
| 9 | Line PG Tap | Line | 61,442 | T1 IN | Xfmr2 | 38,382 |
| 10 | Line PG Jct_WP | Line | 60,652 | T1 PG | Xfmr2 | 36,105 |
| 11 | T1 CL | Xfmr2 | 51,018 | Line IN Tab_IN Sub | Line | 29,502 |
| 12 | Bus VS MAIN | Bus | 44,358 | T2 PG | Xfmr2 | 28,310 |
| 13 | T1 MRM | Xfmr2 | 39,800 | T1 CC | Xfmr2 | 27,719 |
| 14 | T1_EL | Xfmr2 | 39,381 | Line VS_PRD Sw's | Line | 27,291 |
| 15 | T1 IN | Xfmr2 | 38,382 | Bus MRT 60kV | Bus | 24,996 |
| 16 | SW 71 | PD | 38,299 | T1 LN | Xfmr2 | 24,084 |
| 17 | SW 73 | PD | 38,299 | T1_CRL | Xfmr2 | 23,162 |
| 18 | SW 61 | PD | 38,299 | TSpare MRT | Xfmr2 | 22,713 |
| 19 | SW 11 | PD | 38,299 | Line IN Tap_MRT lJct | Line | 22,337 |
| 20 | SW 31 | PD | 38,299 | SW91 | PD | 17,293 |
| 21 | SW 41 | PD | 38,299 | SW90 | PD | 17,293 |
| 22 | SW 51 | PD | 38,299 | T1 NB | Xfmr2 | 16,924 |
| 23 | SW 77 | PD | 38,299 | T1 OL | Xfmr2 | 14,077 |
| 24 | SW 21 | PD | 38,299 | T2 CL | Xfmr2 | 13,104 |
| 25 | T1 PG | Xfmr2 | 36,105 | SW 45_E | PD | 12,541 |
| 26 | CB42+2CT | PD | 33,283 | SW 47 | PD | 12,541 |
| 27 | CB52+2CT | PD | 31,384 | SW 49 | PD | 12,541 |
| 28 | Line IN Tab_IN Sub | Line | 29,502 | SW 27 | PD | 12,541 |
| 29 | T2 PG | Xfmr2 | 28,310 | Line PRD Sw's_CP Tap | Line | 12,490 |
| 30 | T1 CC | Xfmr2 | 27,719 | Line CP Tap_CL Sub | Line | 12,009 |

# Task Five – Final Results

| | | VS System Improvments (%) | | | | PG Improvments (%) | |
|---|---|---|---|---|---|---|---|
| Alternative | Description | SAIFI | SAIDI | EENS | ECOST | EENS | ECOST |
| 1 | Installation of a New 60kV OHL between VS & PG Substation | 3% | 2% | 2% | 2% | 55% | 53% |
| 2 | Installation of a New 60 kV OHL from MRT Sub to PG Substation | 11% | 9% | 8% | 8% | 55% | 53% |
| 3 | Installation of a New 230 kV OHL from TC Sub to PG Jct., Combined with the Erection of a New 230/60 kV Substation at PG Junction | 0% | 19% | 17% | 17% | 93% | 92% |
| 4 | Upgraded VS Substation | 41% | 53% | 54% | 57% | 40% | 42% |

# Project Conclusion

- Commercially Available Software, ETAP, was Utilized
- The VS System was Selected, Modeled and Benchmarked
- The Model Successfully Predicted Reliability Improvements due to Various Investment Alternatives

# Impact of Project on Total Cost of Ownership (TCO)

- Key Systems Can be Modeled and Benchmarked
- Major Contributors to Poor Reliability Can be Identified
- Prospective Reliability Upgrade Projects Can be Identified
- Estimated Project Costs Can be Determined
- All Projects Can be Prioritized on Cost Benefit Scale

Systematic Prioritization of Reliability Improvement Projects

Ensures that Available Budgets are Deployed More Effectively

# Next Steps

- Quantify PUC, Shareholder and/or Customer Goals and Schedules
- Capture Impacts of Upgrades on Remainder of 230kV System
- Capture Other Reliability Related Costs (e.g., Maintenance)
- Capture Reliability Option Upgrade Costs
- Perform Final Cost Benefit Calculations
- Model Other High-Impact Systems and Make System Wide Investment Priority Decisions
- Implement and Expand Reliability Related Component and System Data Capture

# Questions?

# Reminders
# Automation & Power World 2011

- Please be sure to complete the workshop evaluation
- Professional Development Hours (PDHs) and Continuing Education Credits (CEUs):
  - You will receive a link via e-mail to print certificates for all the workshops you have attended during Automation & Power World 2011.
  - BE SURE YOU HAVE YOUR BADGE SCANNED for each workshop you attend. If you do not have your badge scanned you will not be able to obtain PDHs or CEUs.

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