PENNSYLVANIA POWER & LIGHT COMPANY

IMPACT OF EXTENDING THE T-10 AOT FROM 3 TO 7 DAYS

EC-RISK-1050

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1.0 Introduction

The power supply to T-10 is being modified to improve T-10's reliability[1]. The T-10 supply is currently tapped directly off the 47 mile Montour-Mountain 230 kV line. This arrangement exposes T-10 to interruptions for a disturbance anywhere along the 47 miles Montour-Mountain line. Therefore the power supply to T-10 is being modified to improve its reliability. The modification to be installed includes three elements.

The first element consist of segmenting the existing Montour-Mountain line into two new lines. The 18 mile Mountain-T-10 line and the 29 mile Montour-T-10 line. This arrangement will allow T-10 to remain in service following the loss either of the newly constructed lines. Additionally, these lines form an obtuse angle[2] which reduces the exposure of T-10 to an outage caused by tornadoes.

The second element consist of constructing a T-10 tap switch yard with a four bay one and one half breaker arrangement. This design and layout should result in minimum outage exposures to T-10.

Finally, the relaying and control circuits for both T-10 and T-20 will be separated. Currently, the relaying and control equipment is in the same panel in the Susquehanna control room. This equipment will be relocated to the switch gear rooms. Relocating this equipment will:

> eliminate exposure to common cause loss of both T-10 and T-20 during periodic testing of relaying components;
>
> reduce exposure to common cause loss of both T-10 and T-20 to accidental bumping;
>
> provide physical separation of T-10 and T-20 relaying and control equipment.

Together these modifications to T-10 result in a significant improvement in the reliability of T-10 and reduce the common cause outage of both T-10 and T-20.

It is estimated that the construction and installation of these modifications may require T-10 to be out of service for up to 7 days. Current plant Technical Specifications only allow T-10 to be out of service for up to 3 days. Therefore, a dual unit forced shutdown may be required to complete the modification. It was decided to investigate the risk impact of extending the T-10 Allowed Outage Time (AOT) from 3 to 7 days. This calculation documents this investigation.

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[1]Letters to Mr. R. J. Fernandez from D. G . Cole Susquehanna Bulk Transmission Reinforcements, T-10 Tap 230 kV Switchyard. Project Letter. March 27, 1992. and October 19, 1993.
[2]Major Transmission Systems of the Pennsylvania - New Jersey - Maryland Interconnection. PP&L drawing.

2.0 Conclusions

The following conclusions have been derived from this calculation:

- This extension does not impact plant Defense-in-Depth.
- The absolute increase in core damage and/or containment failure frequency is small,
- The application of mitigating measures results in limiting the increase in the relative risk, to less that what is allowed by current plant Technical Specifications.
- The improvements in the T-10 reliability results in a significant decrease in the calculated core and or containment failure probability over the life of the plant.

Based upon these conclusions extending the AOT from 3 to 7 days is justified.

3.0 Methodology

The evaluation of extending the T-10 AOT from 3 to 7 days consisted of three steps. First, the impact of on-line work was assessed using the methodology outlined in NEPM-QA-0900[3]. Second, the increase in core damage and containment failure frequency from extending the AOT from 3 to 7 days was calculated. Third, the reduction in core damage and containment failure frequency from the T-10 improvements was computed. This information was used when evaluating the impact of performing the T-10 improvements with both units on-line.

3.1 Assessment of Performing the T-10 Improvements with Both Units On-line.

NEPM-QA-0900 was used to evaluate the impact of performing the T-10 modifications with both units on-line. The approach used in this procedure depends upon the maintenance rule classification of the SSC being evaluated for on-line work. GDS-18[4] lists the classification of all SSCs at a system level. T-10 is in the maintenance rule scope, but is not risk significant. The evaluation of on-line work activities for non-risk significant SSC consists of the following four steps:

1. Evaluate the total equipment out of service,
2. Determine if the work on the redundant or cross channel SSCs is planned,
3. Determine if work activities can result in a reactor trip, and
4. Identify additional work that can be performed without increasing risk.

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[3]Assessment of On-line Work Windows, NEPM-QA-0900, Rev. 0, DRAFT.
[4]System Scoping for Maintenance rule Applicability, GDS-18, Rev. 1.

This work is being planned for the September/October 1995 time frame. Thus firm work schedules have not been developed. Therefore, the first three steps are performed by identifying what equipment must be operable during the work window. Selection of this equipment is based upon the accident sequences identified in IPE and engineering judgment. Restrictions on equipment that are more severe than Technical Specifications requirements are reported in the Table. These restrictions are imposed to ensure that this equipment is available should a LOOP occur during the T-10 work window.

TABLE 3.1
Restriction on Equipment Outages During the T-10 Work Window

System Structure or Component	Action Should Failure Occur During T-10 Work Window
E diesel in standby, A-D operable	Restore failed diesel ASAP
CRD pumps	Restore failed equipment ASAP
Fire protection water	Restore failed equipment ASAP
Blue Max	Restore failed equipment ASAP
RHR/RHRSW/ESW necessary for suppression pool cooling	Restore failed equipment ASAP
RHR/RHRSW cross tie valves	Restore failed equipment ASAP
HPCI	Shut down
RCIC	Restore failed equipment ASAP
SLCS	Shutdown
CIG 150 psig header and bottles	Restore failed equipment ASAP
TBCCW	Restore failed equipment ASAP
HV-141-F019	Close redundant valve or shutdown

The forth step involves identifying additional maintenance activities that can be performed without increasing the risk during the T-10 modification. Maintenance on T-10 will result in the inability to energize the 4160 switch gear from T-10. Therefore, work on the SSCs between T-10 and the 4160 V switch gear can be performed without increasing the unavailability of the power supply to the switch gear. Furthermore, this work will reduce the likelihood of having to perform work on these components in the future. Therefore it is recommended that maintenance on these components be considered during the T-10 modification window.

3.2 Increase in Core Damage and Containment Failure Frequency from Increasing the T-10 AOT.

The second step in this calculation involves estimating the increase in the core damage frequency from extending the T-10 AOT from 3 to 7 days. This process involved the following steps:

1. identify the dominate accident sequences initiating from LOOP,

2. estimate the increase in the core damage frequency from extending the T-10 AOT from 3 to 7 days, and,.

3. evaluate the risk reduction derived from mitigating actions.

The frequency of core damage and containment failure for Susquehanna was estimated to be 1.1 x 10^{-7} and 4.5 x 10^{-8} respectively[5]. Accidents initiated from LOOP represent about 43% of the core damage frequency, but only 0.2% of the containment failure frequency. Therefore only core damage sequences are evaluated.

A review of the IPE identified the following as the dominate accident sequences initiating from LOOP.

<u>ATWS</u>[6]

LOOP∩{1 ∪ 2 SDV}∩HPCI∩SLCS	Unit 1	1.4 x 10^{-9}.
LOOP∩{1 ∪ 2 SDV}∩HPCI	Unit 2	4.7 x 10^{-8}.

<u>LOOP</u>

LOOP∩D614∩HPCI∩LPP∩{no OSP at 1.8 hours}	2.8x 10^{-11}.
LOOP∩{variety of failures}∩{no OSP at 1.0 hours}	3.0 x 10^{-11}.

<u>SBO</u>

LOOP∩{4 DGs}∩SORV∩RCIC∩{no OSP at 1.0 hours}	1.2 x 10^{-11}.
LOOP∩{4 DGs)∩RCIC∩HPCI∩{no OSP at 1.8 hours}	2.2 x 10^{-11}.
LOOP∩{4 DGs}∩{Blue Max}∩{E DG}∩{no OSP at 6.0 hours}	2.3 x 10^{-11}.
TOTAL	4.9 x 10^{-8}.

The T-10 outage to install the modifications directly impacts the LOOP frequency in that loss of T-20 will directly result in a LOOP. Therefore the increase in the core damage frequency during the T-10 work window can be estimated by scaling the existing damage frequencies by the ratio of the LOOP frequency during the work window to the LOOP frequency used in the IPE. The LOOP frequency used in the IPE is based upon a model

[5]Susquehanna Individual Plant Evaluation, NPE-91-001, December 1991, Vol. 1-6

[6]The accident sequences are different for units 1 & 2 due to installation of the new timing relay on the LPCI throttle valve F017A&B during the 1995 spring outage on unit 1. This modification results in avoiding core damage given HPCI failure provided that SLCS is successful. See Safety Evaluation NL-92-020

described in NUREG-1032[7]. In this model, LOOP events are attributed to four causes: Plant centered, Grid centered, Severe Weather centered and Extremely Weather. The total LOOP frequency of 0.057/year or 0.071/cycle was computed by summing up the frequencies of the various causes.

This modification should only impact the frequency of plant centered LOOPs. Plants centered LOOPs involve hardware failures, design deficiencies, human errors during maintenance or switching, and other common cause events which simultaneously interrupt power to both transformers. With T-10 out of service, single independent failures associated with T-20 will result in a LOOP. The plant centered cause will increase during the outage due to independent faults associated with T-20. Since the increase in the plant centered LOOP frequency is associated with independent faults on T-20, the common cause contribution to plant centered LOOPs remains constant.

This modification is unlikely to impact Grid or Weather centered LOOPs. It is localized to the 47 mile Montour-Mountain line and its connection to T-10. It is not expected that this line outage will significantly destablize the grid. Finally, the modification can in no way influence the weather. Therefore the frequency of grid and weather centered LOOPs should not change during the T-10 work window.

Since the T-10 work window's impact is limited to plant centered LOOPs, only the plant centered LOOP frequency needs to be evaluated for the change during the work window. No specific algorithm was provided in NUREG-1032 for computing the incidence rate of plant center LOOPs. Therefore the plant centered LOOP frequency is taken as the log-normal medium of the common outage rate of T-10 and T-20 . The lower bound is taken as the independent probability of both T-10 and T-20 being unavailable. The upper bound is taken as the 95% confidence limit on the joint outage of T-10 and T-20 based upon zero failures in 7 site years[8] and the chi square distribution[9].

The following equation was used to compute the independent outage rate of both T-10 and T-20 for the current Susquehanna design[10].

$$\lambda_{in} = \text{random line failures} + \text{random transformer failures} + \text{annual line maintenance}$$

$$\lambda_{in} = 2x(\lambda_1\lambda_2)x(8/8760) + \lambda_1 x(72/8760)x(\lambda_1 + \lambda_2) + (8/8760)x(\lambda_1 + \lambda_2) \quad \text{Eq. 3.1}$$

Here,

[7]Evaluation of Station Blackout Accidents at Nuclear Power Plants, NUREG-1032, P. W. Baranowsky June 1988.
[8]The IPE was based upon plant data over the period 1/9/82 to 12/31/89. See NPE-91-001 Vol. 3 page C-1
[9]IEEE Standard 352-1975, General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems.
[10]Internal PP&L Letter from D. G. Cole to P.R. Hill. Subject: Station Blackout Analysis. May 27, 1982.

λ_{in}= the frequency of plant centered LOOPs due to independent causes,
λ_1 = the outage rate of the Montour-Mountain line, (1.3/year),
λ_2 = the outage rate of the T-20 tie line (0.612/year),
λ_t = the failure rate of transformers (0.005/year),
(8/8760) = the fraction of time per year the power supplies to T-10 & T-20 are in maintenance.
(72/8760) = the fraction of time per year required to repair a failed transformer.

The 95% confidence limit on the joint outage of T-10 and T-20 is computed using the following equation:

$$\lambda_{ub} = 5.99/2n \qquad \text{Eq. 3.2}$$

Here n is the number of years under observation. At the time of the IPE evaluation n was 7 years.

These equations are used to compute the lower and upper bound of the LOOP frequency.

$$\lambda_{lb} = 2(1.3)(0.612)(8/8760) + (0.005)(1.3+0.612)(72/8760) + (8/8760)(1.3+0.612) = 0.0033$$

$$\lambda_{ub} = 5.99/(2x7) = 0.43$$

The plant centered LOOP frequency is computed by taking the log-normal medium of these bounds.

$$f_{pc} = \sqrt{\lambda_{lb} x \lambda_{ub}} = \sqrt{(0.0033)x(0.43)} = 0.04/\text{year}$$

This value of 0.04/year represents the yearly frequency of LOOPs due to plant centered causes of which 0.0033/year is a result of independent causes and 0.0367/year is the result of common cause. The frequency of LOOPs from the other causes are: 0.008/year for grid centered, 0.00807/year for severe weather centered and 2.7×10^{-5}/year for extremely severe weather. Summing these together yields a yearly LOOP frequency:

$$f_{tot} = 0.04 + 0.008 + 0.00807 + 2.7 \times 10^{-5} = 0.056/\text{year} = 0.071 \text{ per 15 month refueling cycle}$$

The impact of the T-10 work window on the average cycle LOOP frequency is computed by replacing the annual maintenance time of 8 hours on the T-10 supply in equation 3.1 with the time required for the work window. Two values where chosen: 72 hours which is the T-10 AOT and 168 hours which is the amount of time being requested for modification installation. These two times were chosen since the 72 hours is currently allowed but not used and the 168 hours is the time being requested to install the modification. The yearly frequency of independent plant centered LOOPs becomes:

72 hours

$$\lambda_{1b} = 2(1.3)(0.612)(8/8760) + (0.005)(1.3+0.612)(72/8760) + (8/8760)1.3 + (72/8760)(0.612) = 0.0078$$

This independent frequency is added to the common cause value to obtain the yearly increase in plant centered LOOPs:

$$f_{pc} = 0.0078 + 0.0367 = 0.045/\text{year}$$

$f_{tot} = 0.045 + 0.008 + 0.00807 + 2.7 \times 10^{-5} = 0.061/\text{year} = 0.076$ per 15 month refueling cycle

168 hours

$$\lambda_{1b} = 2(1.3)(0.612)(8/8760) + (0.005)(1.3+0.612)(72/8760) + (8/8760)1.3 + (168/8760)(0.612) = 0.015/\text{year}$$

$$f_{pc} = 0.015 + 0.0367 = 0.052/\text{year}$$

$f_{tot} = 0.052 + 0.008 + 0.00807 + 2.7 \times 10^{-5} = 0.068/\text{year} = 0.085$ per 15 month refueling cycle

These values can now be used to scale the cycle average risk to account for the impact of the T-10 outage.

As described above, LOOP events contribute about 43% of the total core damage frequency. Using this information the impact of this proposed 7 day extension can be computed using the following equation:

$$f_{cd} = \{(1.0 - 0.43) + 0.43x(f_{pc\text{-}mod}/f_{pc\text{-}nomod})\}x1.1x10^{-7} \qquad \text{Eq. 3.3}$$

The increase in the cycle average core damage frequency becomes:

Annual Unavailable Hours	Core Damage Frequency Associated with T-10 Outage Hours	Increase in Calculated Core Damage Frequency
8	$0.57 + 0.43(0.057/0.057)x1.1x10^{-7}=1.1x10^{-7}$	0.0
72	$0.57 + 0.43(0.061/0.057)x1.1x10^{-7}=1.1310^{-7}$	$3x10^{-9}$
168	$0.57 + 0.43(0.068/0.057)x1.1x10^{-7}=1.2x10^{-7}$	$1x10^{-8}$

The current AOT allows a T-10 outage of up to 3 days. Using the full 3 day AOT will result in increasing the core damage frequency by $3x10^{-9}$/cycle. This is about a 3% increase in the cycle average core damage frequency. Increasing the AOT from 3 to 7 days adds an additional $7x10^{-9}$/cycle to the core damage frequency or an additional 6% above what is presently allowed by technical specifications or about 10% greater than present practices.

This analysis provides an estimate of the increase in core damage frequency associated with the T-10 assuming it could occur anytime during the year and with equipment outage during the work window governed strictly by the plant Technical Specifications. However, mitigating measures are being taken to reduce the frequency of core damage during modification outage. These measures include:

1. prohibiting any activity within the confines of the Susquehanna plant or the PP&L grid that may result in a loss of T-20 during the T-10 outage,

2. performing the modification during the fall when the frequency of grid and weather related LOOPs are reduced,

3. requiring a unit shutdown if the HPCI system becomes functionally unavailable during the T-10 outage,

4. requiring a unit shutdown if the SLCS system becomes functionally unavailable during the T-10 outage, and

5. requiring the E diesel to be available as a maintenance spare during the T-10 outage.

The first two measures reduce the LOOP frequency during the T-10 work window, measures 3 and 4 reduce the probability of core damage from ATWS should a LOOP with failure to SCRAM occurs during the work window. Finally, measures 2 and 5 increase the probability that offsite power will be recovered promptly should a LOOP during the T-10 work window. These mitigating measures translate directly into risk reduction during the T-10 outage.

This reduction in core damage frequency is evaluated quantitatively and qualitatively. Quantitative evaluation is limited to the ATWS sequences since they represent more than 99% of the core damage frequency. Qualitative evaluation examines the impact of these mitigating measures on both LOOP frequency and probability of offsite and onsite power restoration. The evaluation of the ATWS sequences is provided first.

The proposed mitigating measures reduced both the frequency of LOOP and the conditional probability of core damage given LOOP. Since the mitigating measures impact both the LOOP frequency and the core damage frequency given LOOP, a scaling of the core damage frequency based upon the impact on cycle average LOOP frequency is not appropriate. The impact of these mitigating measures is ascertained by calculating the core damage frequency assuming the effect of the mitigating measure and then scaling the core damage frequency based upon the length of the T-10 work window (see equation 3.5). Each of these components of risk reduction are evaluated below.

The first mitigating measure significantly reduces Susquehanna's exposure to LOOPs in that work that could cause a loss of T-20 is being prohibited. Therefore loss of T-20 is only the result of random independent faults associated with T-20 and not due to common cause contributors. The impact of this restriction is incorporated into the model by limiting the causes of LOOP to random independent faults associated with T-20.

The impact of performing the T-10 modification during the fall has two aspects. First it reduces the frequency of LOOP events caused by grid and weather centered causes. Second, it substantially reduces the probability of a LOOP of long duration. These impacts can be assessed using the data and correlation provided in NUREG-1032. The reduction in LOOP probability will be evaluated first followed by an evaluation of LOOP restoration.

Grid centered LOOPs occur due to grid instabilities. These instabilities are the result of the grid being at its capacity and a subsequent failure. The grid is at its capacity either during the summer due to air conditioning loads or during the winter due to heating loads. In fact all 14 of the grid related LOOPs reported in NUREG-1032 occurred during the months of April, May, June, July and November. Based upon this data the grid centered LOOP frequency should be no greater than 1/15 of the total grid centered LOOP frequency. This assumes that the next grid centered LOOP occurs during either September or October. Therefore the probability of a grid centered LOOP during September and October is conservatively estimated to be (1/15)x(0.008/year) = 0.0004/year.

Similar arguments can be applied to weather related LOOPs. In this case however, NUREG-1032 provides the following explicit correlation between weather data and weather centered LOOP frequency:

$$f_{SW} = (1.3\times10^{-4})h_1 + bh_2 + (1.2\times10^{-2})h_3 \qquad \text{Eq. 3.4}$$

Here,

h_1 = the mean annual snow fall (in/year),
b = 12.5 for multiple right of ways and 72.3 for single right of ways,
h_2 = the mean annual frequency of tornadoes with wind greater than 113 mph, (events/mi^2-year), and
h_3 = the annual expectation of winds with velocities between 75 and 124 mph, (events/year).

The parameters used in this correlation are presented below:

Parameter	Mean Annual Value	Mean Value for September and October
Snow Fall	49	0.2
Tornado	2.9×10^{-5}	3.7×10^{-6}
High Winds [11]	2.0×10^{-3}	2.0×10^{-3}

Using this data the annual frequency of weather related LOOPs is calculated to be 0.00807/year. Applying the September and October weather data to the Equation 3.4 one computes the incident rate of weather centered LOOPs during these months to be:

$$f_{sw} = (1.3\text{x}10^{-4})0.2 + (72.3)3.7 \times 10^{-6} + (1.2\text{x}10^{-2})\,2.0 \times 10^{-3} = 3.2 \times 10^{-4}$$

Recall the LOOP frequency is the sum of the causes. Therefore the LOOP probability during the T-10 outage becomes the frequency of a T-20 outage, plus the grid and weather related causes or:

$$l_{tot} = 0.612/\text{year} + 0.0004/\text{year} + 3.2 \times 10^{-4} = 0.612/\text{year}$$

Measures are also being taken to reduce the probability of core damage given that the LOOP occurs. Reviewing the accident sequences above one sees that core damage will occur if HPCI fails on unit two or HPCI and SLCS fail on unit one. Current Technical Specifications allow HPCI to be unavailable for 14 days and a SLCS pump for 7 days[12] with T-10 out of service. It is conceivable that these systems could be unavailable during the entire T-10 work window. Therefore, operability of both HPCI and SLCS is required during the T-10 work window. This ensures that these systems will be available should they be demanded.

The risk reduction from requiring that HPCI and SLCS be operable during the T-10 work window is evaluated by setting the maintenance unavailability for these system equal to zero. The probability of core damage then becomes:

$$\text{LOOP}\cap\{1 \cup 2\ \text{SDV}\}\cap\text{HPCI}\cap\text{SLCS} = 0.612\text{x}1.8\text{x}10^{-5}\text{x}0.017\text{x}0.007 = 1.3\text{x}10^{-9}.$$

plus $$\text{LOOP}\cap\{1 \cup 2\ \text{SDV}\}\cap\text{HPCI} = 0.612\text{x}1.8\text{x}10^{-5}\text{x}0.017 = \underline{1.9\text{x}10^{-7}}.$$

TOTAL $1.9\text{x}10^{-7}$/year
$2.3\text{x}10^{-7}$/cycle

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[11] Seasonal variation in wind speeds was not obtained
[12] With two pumps unavailable, Plant Tech Spec require one pump be restored within 8 hours or be in hot shutdown within the next 12 hours.

This number represents the core damage frequency assuming the T-10 work window lasted the entire year. This number must be adjust to reflect the limited time of the T-10 work window. The adjustment is made using the following equation:

$f_{cd} = \{(10950 - t)/10950\} x (4.8x10^{-8}) + (t/10950) x (2.3x10^{-7})$ Eq. 3.5

Here

t = the length of time required to complete T-10 modification, and
10950 = hours in an operating cycle.

72 hours

$f_{cd} = \{(10950 - 72)/10950\} x (4.8x10^{-8}) + (72/10950) x (2.3x10^{-7}) = 4.9x10^{-8}$.

168 hours

$f_{cd} = \{(10950 - 168)/10950\} x (4.8x10^{-8}) + (168/10950) x (2.3x10^{-7}) = 5.1x10^{-8}$.

These numbers represent the core damage frequency for accident sequences initiated from LOOPs. Recall that LOOP events contribute about 43% of the total core damage frequency. The total increase in core damage is calculated using equation 3.3:

72 hours

$f_{cd} = \{(1.0 - 0.43) + 0.43x(4.9/4.8\} x1.1x10^{-7} = 1.11 x 10^{-7}$

168 hours

$f_{cd} = \{(1.0 - 0.43) + 0.43x(5.1./.4.8)\} x1.1x10^{-7} = 1.13x10^{-7}$.

Therefore the mitigating actions reduce the increase in core damage to about 2% above normal practices. This is about a factor of 5 less than the increase when no mitigating measure are imposed. In fact these measure reduce the increase in core damage frequency to below what is allow by present technical specifications (the 72 hour case with no mitigating actions). Therefore this work can be performed within the risk envelope allowed by the plant Technical Specifications.

In addition to the quantitative improvements in core damage frequency associated with the mitigating measure identified above, additional benefits are also derived which have not been quantified. These are performing the modification when the LOOPs of greater duration are less likely to occur and requiring that the E diesel be available in standby prior to the commencing the T-10 modification.

Recall that NUREG-1032 classified LOOP events into three categories: plant centered, grid centered and weathered centered. The medium duration of LOOPs in each category is 0.3 hours, 0.6 hour and 3.5 to 4.5 hours respectively. As shown above, performing this modification during September or October effectively eliminates both grid and weather related LOOPs. Therefore the probability of a sustained LOOP[13] is substantially reduced.

In the rare event that an extended LOOP occurs, restrictions have been placed upon diesel maintenance to ensure that the E diesel is available to substitute for any diesel that may fail should during the LOOP. This requirement reduces the probability that the E diesel will be unavailable or failed by about a factor of 10.

Thus these mitigating measures have reduced the probability of an extended LOOP and ensured a high availability of onsite AC power. This has substantially reduced the chance of extended station blackout.

3.3 Improvements to Risk Profile from T-10 Improvements.

The modifications to T-10 were motivated by the desire to improve the reliability of the power supplies to T-10. The improvements, as described in the Introduction, reduce the frequency of both independent and common cause losses of the power supplies to Susquehanna. The reduction in LOOP frequency derived from these improvements will result in a decrease in the core damage frequency. This reduction in core damage frequency is estimated by first determining the reduction in LOOP frequency and then scaling the total core damage frequency using equation 3.3. The impact of these improvements are estimated using the methodology developed in NUREG-1032 and described in Section 3.2.

The proposed modifications directly impact both the independent and dependent causes of plant centered LOOPs. Segmenting the Montour - Mountain line result in two independent lines providing power to T-10. This significantly improves the reliability of the power supply to T-10. Relocating the relaying and control equipment for both T-10 and T-20 from 0C657 to separate switch gear rooms significantly reduces the probability of common cause trip of both T-10 and T-20 during test and maintenance on these circuits. Therefore one would expect a reduction in the plant centered LOOP frequency.

The independent outage rate of both T-10 and T-20 is computed as described in Section 3.1:

λ_{in} = random line failures + random transformer failures + annual line maintenance[14].

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[13]Core damage occurs at about 80 minutes (1.33 hours) following scram during station blackout. The mean time to restore an offsite circuit for a single switch yard plant is reported in NUREG 1032 is 0.78 hours. Assuming an exponential recovery model the probability of recovering offsite power prior to core damage is 82%. 1.0 - exp(-1.33/0.78) = 0.82.

[14]Annual line maintenance is assumed to occur once per year. Therefore the unit of once per year is inferred in the term for annual line maintenance

$$\lambda_{in} = 3(\lambda_1\lambda_2\lambda_3)(8/8760)^2 + \lambda_t\{(72/8760)^2(\lambda_1\lambda_2) + (72/8760)\lambda_3\} + (8/8760)^2 x(\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_2\lambda_3) . \quad \text{Eq 3.6}$$

Here,

λ_1 = the outage rate of the 18 mile Mountain - T-10 line (0.45/year)[15],
λ_2 = the outage rate of the 29 mile Montour -T-10 line (0.73/year),
λ_3 = the outage rate of the T-20 tie line (0.61/year), and
λ_t = the failure rate of transformers (0.005/year).

The independent LOOP frequency after the installation of the T-10 modifications becomes:

$$\lambda_{in} = 3(0.45x0.73x0.61)(8/8760)^2 + 0.005\{(72/8760)^2(0.45x0.73) + (72/8760)0.61 + (8/8760)^2x(0.45x0.73 + 0.45x0.61 + 0.73x0.61) .$$

$\lambda_{in} = 2.7 \times 10^{-5}$.

These modifications result in a 100 fold decrease in the frequency of plant centered LOOPs due to independent failures. This frequency is assumed to be the lower bound of the plant centered LOOP frequency. Recall equation 3.2 was used to compute an upper bound plant centered LOOP frequency of 0.43. The new plant centered LOOP frequency is then estimated using the log-normal medium:

$$f_{pc} = \sqrt{\lambda_{lb} x \lambda_{ub}} = \sqrt{2.7 \times 10^{-5} x(0.43)} = 0.0034/\text{year}.$$

Therefore the modifications result in a 10 fold decrease in the plant centered LOOP frequency.

Since the analysis performed to generate the IPE (NPE-91-001), five additional years have transpired without a LOOP. This additional data should reduce the upper bound of the plant centered LOOP frequency. Using this data the upper bound becomes:

$$\lambda_{ub} = 5.99/2n = 5.99/(2x12) = 0.25/\text{year}.$$

The plant centered LOOP frequency, when accounting for the plant modifications and the additional data becomes:

$$f_{pc} = \sqrt{\lambda_{lb} x \lambda_{ub}} = \sqrt{2.7 \times 10^{-5} x(0.25)} = 0.0026/\text{year}.$$

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[15]Outage rates for the Mountain - T10 and Montour - T-10 lines are computed using the data in reference 10. λ_1 = (18 miles) x (0.025 line outages/mile-year) = 0.45 outages/year and
λ_2 = (29 miles) x (0.025 line outages/mile-year) = 0.73 outages/year

Segmenting the Montour - Mountain line also improves the ability of T-10 to remain energized during sever weather. Recall in Eq. 3.4 parameter b was either 12.5 or 72.3, depending on the number of right of ways. The number of right of ways is important when evaluating the odds of a single tornado failing all the offsite power lines feeding the plant. Presently, all the power lines feeding Susquehanna are parallel crossing the Susquehanna river. However, after segmenting the Montour - Mountain line, the Mountain - T-10 will terminate North of the river, resulting in two right of ways. The impact of this improvement is computed using equation 3.4:

$$f_{sw} = (1.3\text{x}10^{-4})49 + (12.5)2.5 \text{ x } 10^{-5} + (1.2\text{x}10^{-2})\ 2.0 \text{ x } 10^{-3} = 6.7 \text{ x } 10^{-3}$$

The LOOP frequency becomes:

$\lambda_{tot} = 0.0034 + 0.008 + 0.0067 + 2.7 \text{ x } 10^{-5} = 0.018/\text{year} = 0.023$ per 15 month refueling cycle.

This post modification LOOP frequency is used in equation 3.3 to estimate the reduction in core damage frequency associated with the modification.

$$\lambda_{cd} = \{(1.0 - 0.43) + 0.43\text{x}(0.023/0.071\}\text{x}1.1\text{x}10^{-7} = 7.8\text{x}10^{-8}.$$

This represents about a 30% decrease in the core damage frequency due to the modification.