Assessment of Loss of Offsite Power Initiating Event Frequency

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ABSTRACT

The initiating event known under the term loss of offsite power is one of dominant risk contributors in many nuclear power plants. Its event tree with consequent end states and its related event tree station blackout with its consequent end states represent the connection between power system reliability and nuclear power plant safety. The methods for assessing initiating event loss of offsite power frequency are reviewed and improved. The frequency is assessed and the current plant status and power system are compared to the plant status and power system status from years ago. The results are similar to the results of other similar power plants.

1 INTRODUCTION

The initiating event known under the term loss of offsite power has been one of dominant risk contributors in many nuclear power plants. Its event tree and its related event tree station blackout with their consequent end states represent the connection between the power system reliability and the nuclear power plant safety. Because of the importance of the issue, the questions related to the electric power system reliability have been investigated well ago [1], [2] and have been increasingly under attention in the last years, which significantly reduced the related risk. The objective of the paper is to review existing methods for evaluation of the loss of offsite power initiating event frequency and to develop their improvements in order to assess the loss of offsite power frequency in a better way. It is necessary to consider that one nuclear power plant exists in Slovenia, which consequently means a lack of data connected with events, which occur rarely, which is certainly true for the loss of offsite power. The methods from the country of our nuclear power plant origin represent the standpoint for the review, so the standards and guidelines as used in USA are applicable for Slovenia, wherever the domestic and European standards and guidelines are not available.

2 METHODS

The methods for assessing the initiating event loss of offsite power frequency are reviewed [3], [4], [5], [6], [7]. Slight improvements are developed.

2.1 Review of Existing Methods

\[ f_{\text{severe\_weather}} = 1,3 \cdot 10^{-4} \cdot h_1 + b \cdot h_2 + 0,012 \cdot h_3 + c \cdot h_4 \] (1)

\( h_1 \) – annual expectation of snowfall in inches (for the nuclear power plant site)

\( h_2 \) – annual expectation of tornadoes with wind speeds greater than or equal to 113 miles per hour per square mile per site

\( b = 12,5 \) for sites with transmission lines on two or more rights-of-way spreading out in different directions from the switchyard

\( b = 72,3 \) for sites with transmission lines on one right-of-way spreading out from the switchyard

\( h_3 \) – annual expectation of storms at the site with wind velocities between 75 and 124 miles per hour

\( h_4 \) – annual expectation of hurricanes at the site

\( c = 0 \) if switchyard is not vulnerable to the effects of the salt spray

\( c = 0,78 \) switchyard is vulnerable to the effects of the salt spray

\( f_{\text{severe\_weather}} \) – loss of offsite power initiating event frequency due to severe weather

Regulatory Guide RG-1.155 intends to classify nuclear power plants into groups regarding severe weather. For each of those groups, the range of initiating event loss of offsite power frequency is determined (severe weather group 1 or 2 or 3 or 4 or 5). Regulatory Guide RG-1.155 intends to classify nuclear power plants into groups regarding extremely severe weather and for each group the range of initiating event loss of offsite power frequency is determined (extremely severe weather group 1 or 2 or 3 or 4 or 5). In addition, RG-1.155 classifies plants into groups regarding the station blackout coping capability, regarding configuration of electric power system in the nuclear power plant in terms of design and in terms of a number of independent power sources.

The method for assessing the loss of offsite power frequency is widely documented in NUREG-1032 [5]. The causes for the loss of offsite power are considered separately from each other and the loss of offsite power frequency is determined for each of them: for plant induced failures, for grid induced failures, for severe weather induced failures and for extremely severe weather induced failures.

Each nuclear power plant is grouped into several groups regarding the causes for the loss of offsite power. The initiating event frequency is determined for every cause separately. The sum of initiating event frequencies \( f(t) \) for all causes gives the overall loss of offsite power frequency, which is evaluated and further used in the probabilistic safety assessment.

\[ f = f_{\text{plant\_induced}} + f_{\text{grid}} + f_{\text{severe\_weather}} + f_{\text{extremely\_severe\_weather}} \] (2)

\( f_{\text{plant\_induced}} \) – loss of offsite power initiating event frequency due to plant induced failures

\( f_{\text{grid}} \) – loss of offsite power initiating event frequency due to grid failures

\( f_{\text{severe\_weather}} \) – loss of offsite power initiating event frequency due to severe weather

\( f_{\text{extremely\_severe\_weather}} \) – loss of offsite power initiating event frequency due to extremely severe weather

The loss of offsite power initiating events and their duration are considered. The curves are developed by fitting data to two parameter Weibull function.

\[ f_{\text{L0TP}}(t) = f_{\text{L0TP}} \cdot e^{-(\alpha t)^\beta} \] (3)
\( f_{\text{LOOP}_i} \) - loss of offsite power initiating event frequency due to cause \( i \) \{plant induced; grid; severe weather; extremely severe weather\}

\( \alpha, \beta_i \) – parameters of Weibull distribution

\( t \) – duration of loss of offsite power event

NUREG/CR-5496 [6] was issued later than previous documents and serves to collect more data compared to previously issued documents. NUREG/CR-6890 [7] introduces new category: switchyard, and joins severe weather and extremely severe weather categories. The evaluation uses Gamma distribution for each particular category data and summarizes the frequency weighted contributions. Each category for initiating event frequency evaluation is based on Bayesian update.

\[
f_i = f_{\text{posterior mean}_i} = \frac{\alpha + n_i}{\beta + T_i}
\]

\( \alpha \) - prior gamma distribution shape parameter

\( \beta \) - prior gamma distribution scale parameter

\( n_i \) – number of loss of offsite power events due to category \( i \)

\( T_i \) – number of years considered

NUREG/CR-6890 distinguishes the plant operation state from plant shutdown state. The data show that the loss of offsite power is approximately four times more frequent at plant shutdown compared to plant operation.

\[
f = f_{\text{op}} \cdot \frac{t_{\text{op}}}{t_{\text{op}} + t_{\text{sh}}} + f_{\text{sh}} \cdot \frac{t_{\text{sh}}}{t_{\text{op}} + t_{\text{sh}}}
\]

\( f_{\text{op}} \) – loss of offsite power initiating event frequency for the time of plant operations

\( f_{\text{sh}} \) – loss of offsite power initiating event frequency for the time of plant shutdowns

\( t_{\text{sh}} \) – time of plant shutdowns

\( t_{\text{op}} \) – time of plant operations

Data for supporting the calculation method from NUREG/CR-6890 is updated yearly, which is presented in references [8], [9], [10], [11], [12].

2.2 Methods Improvements

Due to lack of data in Slovenia, there is no need to distinguish the data according to four categories. Only one loss of offsite power occurred in year 1986 and lasted for an hour and 15 minutes when the plant was in shutdown. So, equation can be the following.

\[
f(t) = f_{\text{plant induced}}(t) + f_{\text{switchyard}}(t) + f_{\text{grid}}(t) + f_{\text{severe weather}}(t)
\]

The equation (1) needs to be expanded due to sleet although the data about sleet is difficult to obtain quantitatively.

\[
f_{\text{severe weather}} = 1.3 \cdot 10^{-4} \cdot h_1 + b \cdot h_2 + 0.012 \cdot h_3 + c \cdot h_4 + d \cdot h_5
\]

\( h_5 \) – annual expectation of sleet causing additional load to power lines exceeding own weight for 100% or more

\( d \) – factor of sleet impact (\( d=0; \) if sleet is not applicable at the site)
In order to reduce the uncertainty of the results, the generic data should be combined with specific data in some extent. The weighted average considering the generic and specific data gives the loss of offsite power frequency.

\[ f = k_{USA} \cdot f_{USA} + k_{SI} \cdot f_{SI} \]  

(8)

\( f_{USA} \) - initiating event frequency according to the latest generic data, e.g. ref. [12]

\( f_{SI} \) - initiating event frequency according to the specific data in Slovenia

\( k_{USA} \) - weight factor (approximately 100 plants in USA, but generic data)

\( k_{SI} \) - weight factor (1 plant in Slovenia, but specific data)

\( k_{USA} = 0,5 \)

\( k_{SI} = 0,5 \)

Both frequencies: \( f_{USA} \) and \( f_{SI} \) are evaluated according to the data of NUREG/CR-6890 and its updates and according to the specific data for Slovenia, respectively.

The new features of the electric power system in the vicinity of the site include increasingly used distributed sources of electric energy with power dependency on weather parameters [13], [14], [15].

3 ANALYSIS AND RESULTS

The frequency of the loss of offsite power is assessed and the current plant status and the power system topology are compared to the plant status and the power system topology from years ago. The assessment is evaluated considering the data collected over the years of plant operation. The improvements of the system configurations include new power lines, new hydro power plants in the vicinity of the nuclear power plant, improved switchyards connecting nuclear power plant with electric power system.

Specific data

1 event in 36 years can give a frequency of 0,028 per reactor per year.

Figure 1 shows variations of data fit according to NUREG-1032, which is based on Weibull distribution.

Generic data from reference [12]

\( f = 0,0299 \) per reactor per year (for the plant in operation)

\( f = 0,172 \) per reactor per year (for the plant in shutdown)

Results

The loss of offsite power frequency for the plant operation is evaluated as 0,029 per reactor per year.

Figure 2 shows the power system from decades ago. Figure 3 shows the current state of power system. DS stands for distribution station, DTS for distribution transformer station, TPP for thermal power plant, HPP for hydro power plant, DG for diesel generator.

Some components have not failed in the last 13 years (from year 2000). Some of them have evidence on some faults, but they are rare and of short duration. 400 kV lines are out of operation due to planned events around 5 % of time. 400 kV lines are out of operation due to unplanned events very rarely: typical example: one power line in the last 13 years was 3 times...
down with the joined downtime of 6 hours in 13 years. Typical power transformer was down for less than half an hour in its 7 years of operation due to one event. 110 kV lines are out of operation due to planned events for less than 1% of time. 110 kV lines are out of operation due to unplanned events very rarely: typical examples include power lines that have not experienced any events in the last 7 years, while one particular power line is yearly out once for approximately half an hour. The grid contribution to the loss of offsite power frequency seems to give much smaller numbers as it is a generic value of 0.0117 per reactor per year [12].

Figure 1: Weibull data fit - the frequency of loss of offsite power according to NUREG-1032
Figure 4 shows the evolution of the loss of offsite power frequency in USA and in Slovenia through the years. For the last 20 years, the frequency in Slovenia was determined around 0.05 per reactor per year in spite of the constant improvements of the equipment and the power system topology related to the plant switchyard and its connections to the transmission system.

Figure 2: Power system - 20 years ago

Figure 3: Power system – current state
The last important upgrade of safety is installation of the third diesel generator DG3, which primarily serves as an alternative power source although in its secondary role it can serve as the backup for any of two plant diesel generators, which are not shown on the figures.

![Diagram showing frequency of loss of offsite power per reactor per year for USA and SI](image)

Figure 4: Evolution of data through the years in USA and in Slovenia

No wind power plant operates in the vicinity of the nuclear power plant site. The number of solar power plants in the vicinity exceeds 40 with their joined peak power of approximately 4 MW. At the moment, they do not represent any threat for reduced reliability of the power system neither the plant safety. In the future, the distribution system operator and the transmission system operator will need to consider the issue of quantity of renewable power in the terms of nuclear safety, if their number is raised, significantly.

New hydro power plants were built in the vicinity, which can have positive impact to the power system reliability and nuclear power plant safety. Monitoring of System Average Interruption Frequency Index for Slovenian power transmission system can give indication of reliability of transmission system [16]. This is of special importance for the future, because the worldwide weather events cause more problems in the last decade compared to the previous decade, which includes the fact that the number of annual deaths per million population due to droughts, earthquakes, floods, storms increased for a factor of 3 worldwide in spite of the more modernised world [17].

4 CONCLUSIONS

The existing methods for evaluation of the loss of offsite power initiating event frequency were reviewed. The improvements were developed in order to assess the loss of offsite power frequency in a better way considering the lack of data connected with the events, which occur rarely in Slovenia but keeping the importance of specific data.

The loss of offsite power frequency is calculated. It is compared to the previous results and to the generic results.

The power system in the vicinity of the nuclear power plant is evaluated and compared to the situation from years ago. Significant improvements were made for improvement of the power system reliability, which consequently shows reduction of the loss of offsite power frequency.
REFERENCES


