

## **Effects of Future Uncertainty on Present-day Asset Management**

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### **SUMMARY**

Probabilistic methods for risk assessment and management become more uncertain when looking further into the future. A typical electrical utility risk assessment considers a ten-year time period to forecast the expected development of load, asset condition, and other system features. When trying to forecast further than ten years out or predict fundamental changes to the nature of the grid, the risk assessment becomes less certain.

The role of the electric utility asset manager is to proactively balance present-day investment into asset maintenance, sustainment, and system expansion against future risks facing the utility in order to meet the utility's asset management objectives. Taking a long-term view of asset management, there is a high degree of uncertainty regarding the nature of the future grid and external factors affecting the utility's risk assessment. For instance, while the industry agrees that the widespread use of electric vehicles is coming, the timing and degree of proliferation are highly uncertain. This paper explores future uncertainties affecting the power industry and offers strategic implications for present-day asset management.

Major and far-reaching areas of future uncertainty in the power industry include the widespread use of electric vehicles, behind-the-meter generation, microgrids, peer-to-peer energy transactions, the effects of carbon pricing. Other major areas of future uncertainty exist due to global climate change effects such as increased storm frequency and intensity, rising sea levels, shifting wind patterns, more extreme cold snaps and/or heatwaves, and increased risk of bushfires, depending on the localized effects. While the timing and fruition of uncertain events are unpredictable by nature, utilities can conduct planning exercises to prepare for a range of future states. The presented planning framework covers examination of a range of outcomes, predicting possible impacts of these outcomes, calculating the risks of these impacts based on likelihood, discounting future risks to a present-day value, and then analyzing the implications for present-day investment decisions. The framework considers a robust set of asset management options including either an increase or deferral of capital sustainment, capital expansion, and system maintenance depending on the impacts. For example, carbon pricing may reduce sustainment needs for one area of the grid connecting

thermal coal plants in favour of funding system expansion to increase wind dispatch capabilities.

Exploring the range of outcomes introduced in the previous paragraph, the framework is applied through robust discussion, reasonable assumptions, and economic analysis. By starting with a ten-year outlook and shifting up to twenty-five years forward, future uncertainties are systematically catalogued, assessed, and planned for where reasonable. This exercise will yield insights into the nature of the grid of the future and provide strategic direction that companies can take in the response.

## **KEYWORDS**

Asset management, future uncertainty, probabilistic methods, risk assessment, risk management, grid of the future, climate change

## 1. INTRODUCTION

The electricity sector is undergoing fundamental changes that introduce extraordinary uncertainty surrounding future market and operating conditions. There are three substantial areas of change contributing to this uncertainty. Firstly, adapting the grid to the customer of the future will necessitate accommodation of electric vehicles (“EVs”), behind-the-meter generation, microgrids, and peer-to-peer energy transactions at an unprecedented scale. Secondly, the effects of carbon pricing and greenhouse gas emissions will shift the generation mix away from fossil fuels towards renewables. Emissions of sulfur hexafluoride (“SF6”) gas, a common insulating medium for electrical equipment, may also common under more intense scrutiny or regulation. Finally, global climate change effects will likely result in greater storm frequency and intensity, rising sea levels, shifting wind patterns, more extreme temperatures, and increased risk of bushfires.

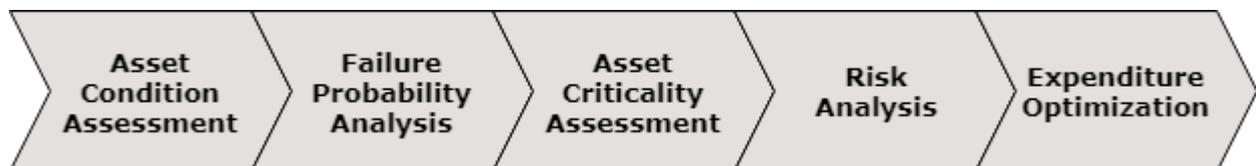
The degree of uncertainty intensifies when considering longer planning horizons. The role of the electric utility asset manager is to proactively balance present-day investment into asset maintenance, sustainment, and system expansion against future risks facing the utility in order to meet the utility’s asset management objectives. Thus, the application of systematic risk-based asset management will be fundamental to successfully adapting to these changes.

## 2. ESTABLISHED ASSET MANAGEMENT PRINCIPLES

The electricity sector has adopted the implementation approach for asset management systems described in the ISO 55000 series of standards, which requires utilities to conceive asset management objectives and develop plans to achieve them [1]. For the management of physical assets, a common objective is to minimize the total cost of ownership (“TCO”) over the lifetime. A risk-based asset management approach can minimize TCO by optimizing investments throughout an asset’s life-cycle. Fundamentally, risk at an individual asset level is the product of an event’s probability and its consequences. Utility asset managers concentrate on making proactive investment decisions to avoid a forced outage.

$$\text{Asset Risk} = \text{Consequences of Outage} * \text{Probability of Outage}$$

The key steps of a risk-based asset management approach are briefly outlined in Figure 1. The asset condition assessment systematically evaluates the physical degradation of assets used to estimate the probability of a forced outage. Asset criticality assessment identifies the consequences of the forced outage based on the asset’s role in the system. The risk analysis on an individual asset level is then used to optimize expenditures by minimizing TCO.

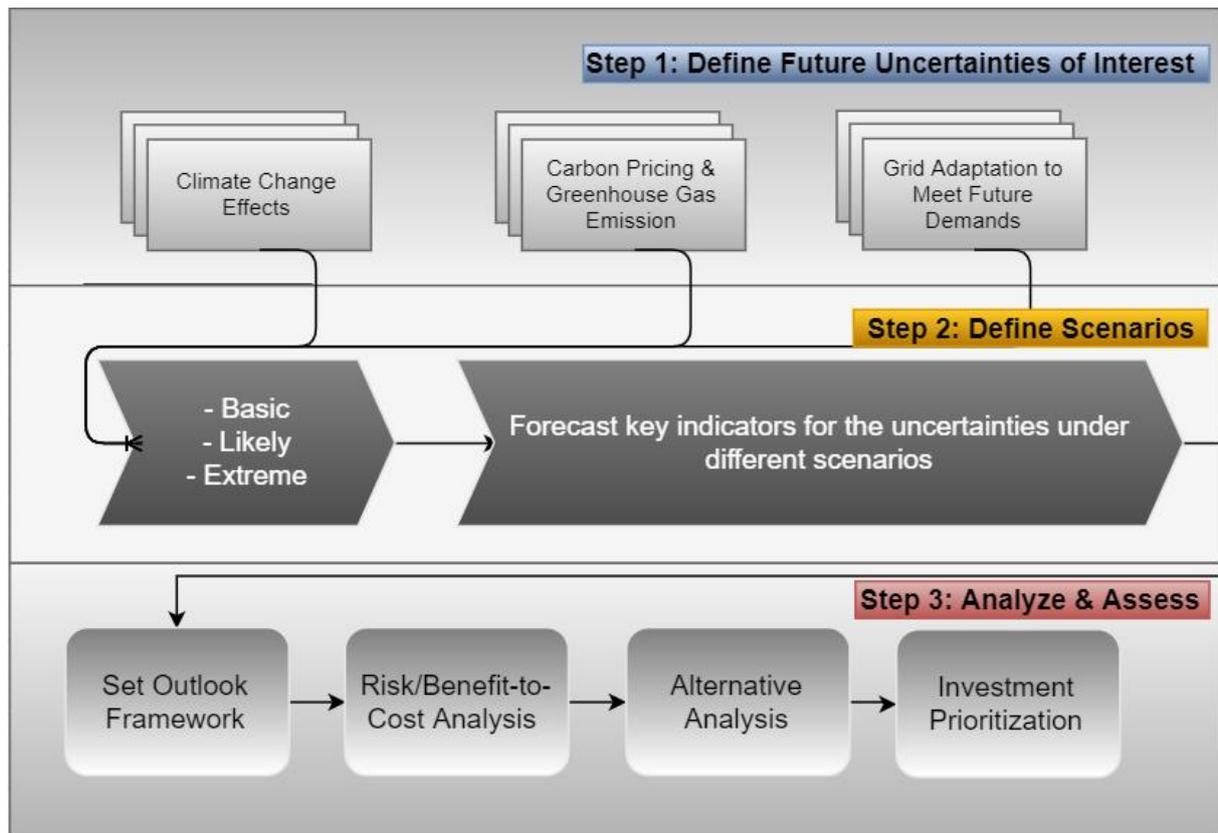


**Figure 1: Key steps of a risk-based asset management approach**

By applying good asset management practices and following the steps above, the utility asset manager can decide when a specific asset warrants replacement, repair or refurbishment, and can prioritize their limited resources to ensure expenditures are efficiently allocated from an economical perspective.

### 3. UNCERTAINTY FRAMEWORK OVERVIEW AND APPLICATION

The evolution of electrical vehicles, microgrids, and behind-the-meter generation will require grid operators to manage the system and assets within them in different ways to achieve a reliable and grid compliant future supply. Environmental agreements and legislations are shifting the electricity sector away from fossil fuels and towards renewable. Global climate change effects are transforming utility operating conditions. The range and depth of future uncertainties suggest that a systematic approach is needed to assess and evaluate future scenarios. Figure 2 illustrates the proposed approach to quantify and manage future uncertainties.



**Figure 2: Overview of Uncertainty Framework**

#### **Step 1: Define Future Uncertainties of Interest**

The electricity supply will be influenced in the coming decades by several developments that will have a substantial impact on the market and operating conditions of the electrical system [4]. Three areas of future uncertainties that will impact the energy sector are summarized.

##### **a) Grid Adaptation to Meet Future Demands**

The widespread proliferation of EVs will have a considerable impact on the grid since their societal integration will demand significant network development to accommodate higher load and more complex consumption patterns. This will affect the electricity market conditions by constraining the network due to overloading, congestion, and energy losses [7]. Investments into energy generation, storage, and grid enhancements can address these changes.

To adapt to the ever-growing electricity demand, the grid composition is moving away from conventional one-way power flow through an interconnected network and pivoting towards the prevalence of microgrids and behind-the-meter generation. These solutions offer distinct advantages to utilities and customers such as a reduction in energy consumption, improvement in energy efficiency, reduction in greenhouse gas and carbon emissions, improvement to operation and supply, and cost-effective solution to electricity infrastructure replacement.

### ***b) Carbon Pricing and Greenhouse Gas Emission***

To keep the global temperature rise below limits defined in the Paris Accord, the electricity sector must move away from emission-producing power (i.e. coal, gas, and oil) to more renewable power generation such as hydropower, wind, and solar. While there are significant benefits to renewable energy generation, there are also challenges associated with the increased intermittency of the generation mix. In some cases, renewables can require extensive investment into power transmission from large generation sites, which are often greenfield projects (e.g. solar farms in deserts and remote offshore wind farms). For distributed generation, a reverse power flow may occur, which can be an undesirable situation and can be detected using bidirectional relays. Additionally, renewable energy integration will likely require distributed or grid-scale energy storage units including batteries [4],[7].

As a greenhouse gas, SF6 is over 20,000 times more potent than carbon dioxide. To reduce the climate change impacts related to SF6 gas emissions, the industry is developing new alternatives that are SF6 free and existing SF6-insulated equipment must be managed [4].

### ***c) Climate Change Effects***

Global climate change effects are becoming more profound and noticeable. Rising sea levels, more extreme temperature days, bushfires, severe storms, and shifting wind patterns are among the key areas of concern. It is important for the power sector to understand the challenges associated with climate change and act upon them in an appropriate manner.

Sea levels are expected to rise in the next century putting power plants and other electricity infrastructure at greater risk of damage and outages due to flooding. A recent study estimates that 100 power plants and substations are located within four feet of local high tide in the United States, making them vulnerable to higher water levels and storm surges [9].

The changes to air temperatures have led to several challenges such as drier forests and earlier snowmelts that increase the vulnerability of power sector infrastructure. One demonstrative example is bushfires which can cause extensive infrastructure damage and power outages. Pole fires (i.e. due to arcing) risk catastrophic escalation into a bushfire.

The change to water temperatures can cause many issues to power plants. Thermal power plants rely on water to condensate the steam to run the turbines. Higher temperatures reduce the plant's efficiency and, in some cases, create unsafe conditions to the local ecosystem, necessitating a temporary plant shut down [9].

## **Step 2: Define Scenarios**

Once areas of future uncertainties are identified according to the utility's unique operating environment, the next step is to define probabilistic scenarios for each area. At a minimum, three scenarios should be considered:

1. Base Case: the current state ignoring future uncertainties.
2. Likely Scenario: the anticipated occurrence of an event defined based on historical trends, estimation models, and subject matter experts.
3. Extreme Scenario: a subset of the likely scenario describing effects that may occur but which are less likely.

Key indicators for the uncertainties should be forecast for different scenarios. To illustrate this, Table 1 describes possible key indicators of future uncertainties under three probabilistic scenarios. Utilities employing this methodology should develop unique forecasts according to their operating conditions.

**Table 1: Scenario Assumptions for Areas of Future Uncertainties**

<b>Uncertainty</b>	<b>Base Case</b>	<b>Likely Scenario</b>	<b>Extreme Scenario</b>
<b>EVs including hybrids</b>	0.3% of vehicles	15% of vehicle sales	50% of vehicle sales
<b>Behind-the-meter generation</b>	10% of generating capacity	25% of generating capacity	40% of generating capacity
<b>Microgrids</b>	Pilot programs in some networks	Pilot programs in most networks	Prevalence of multi-microgrid networks
<b>Peer-to-peer energy transactions</b>	Not implemented	Opt-in programs in place	Complete market overhaul
<b>Increase in installed capacity for renewables</b>	Accounting for installed and planned projects only	Global CAGR: 8% solar PV, 5% wind	global CAGR: 11% solar PV, 8% wind
<b>Less fossil fuels</b>	Existing plants kept in service	Dirtiest coal plants shut down	All coal plants shut down
<b>Management of SF6 leaks</b>	Replacement of leaking equipment	Replacement of equipment likely to leak	Change-out of all SF6 equipment
<b>Storm frequency and intensity</b>	Reverts to previous decade's levels	Stabilizes at current levels	Continues to rise
<b>Rise in global average sea levels</b>	5-cm rise	15-cm rise	30-cm rise
<b>Changes in wind patterns</b>	Current wind speeds	+/- 0.1 m/s on average	+/- 0.2 m/s on average
<b>Extreme hot/cold weather</b>	5% increase in peak load	10% increase in peak load	20% increase in peak load
<b>Bushfire frequency and intensity</b>	Reverts to previous decade's levels	Stabilizes at current levels	Continues to rise

**Step 3: Analyze and Assess**

At the outset of analysis, the utility should set the outlook timeframe that they wish to explore. It is recommended to consider a minimum of 10 years and a maximum of 25 years. Once determined, risk mitigation strategies can be utilized for each future certainty under each scenario to quantify the effects on present-day investments. We summarize the assessment process as follows:

1. Identify systems and subsystems that could be affected by the identified areas of future uncertainties.
2. Set outlook timeframe for analysis (ten years or greater).
3. Analyse the effects of those future uncertainties under each scenario utilizing the identified key indicators or weighting factors.
4. Perform risk mitigation analysis.
5. Evaluate the benefits and costs of different options, quantifying all risks into monetary terms and balancing these risks against the capital expenditures required to offset the risks.
6. Prioritize investment plans based on corporate goals and regulations for each scenario.

Table 2 demonstrates the system effects and asset management impacts of the aforementioned uncertainties facing the power industry.

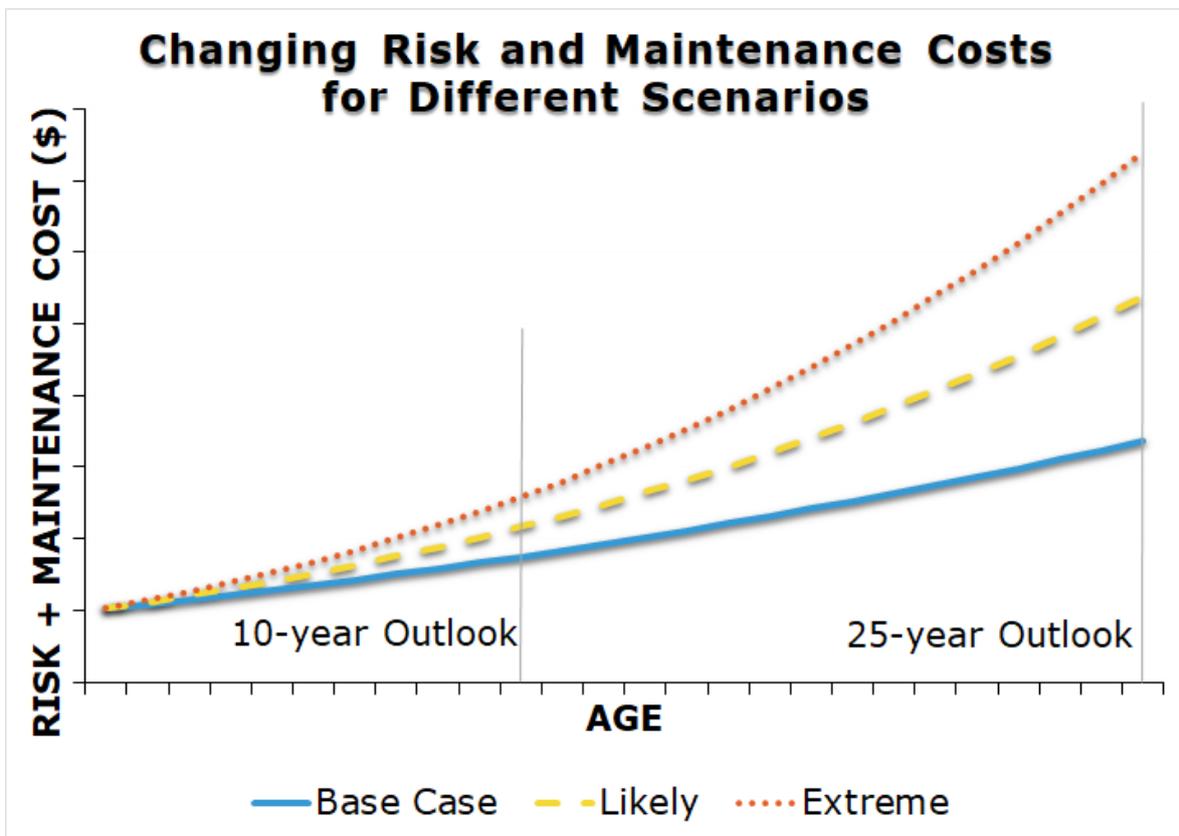
**Table 2: Anticipated effects of the various areas of future uncertainties on the power industry**

<b>Uncertainty</b>	<b>System Effects</b>	<b>Asset Management Impacts</b>
<b>EVs</b>	Potential for peak loading will necessitate customer-side and grid-connected energy storage, intelligent charging, and bidirectional transactions	Higher value of electricity Increased load More thermal deterioration
<b>Behind-the-meter generation</b>	Less consumption from the grid, same capacity ratings, increased harmonics and transients, increased risk of reverse power flow	Decreased load Decreased reliability impacts Less thermal deterioration
<b>Microgrids</b>	Less electricity from the bulk system, capacity upgrades required, improved power quality	Decreased load Decreased reliability impacts Less thermal deterioration Deferral of capacity upgrades
<b>Peer-to-peer energy transactions</b>	Less transmission, customers more responsive to price	Less thermal deterioration on the transmission system Deferral of capacity upgrades
<b>More renewables</b>	More transmission which tends to be greenfield sites Increased reliance on reactors and phase-shifting transformers Offshore connections to onshore networks Increased risk of reverse power flow for DG	More assets to manage
<b>Less fossil fuels</b>	Specific transmission lines/substations become unused when plants close, plants may be retrofitted as in Ontario	Deferral of asset sustainment investments Management of line retirement projects
<b>Management of SF6 leaks</b>	More emphasis on SF6 equipment management over its life-cycle, including maintenance and capital programs Particular emphasis on older vintage SF6 units, more prone to leakage	Monetization of SF6 emissions Dedicated asset maintenance and sustainment programs
<b>Storm frequency and intensity</b>	Greater need for storm response, predictive analytics, targeted investment and maintenance, and large-scale restoration plans	Increased mechanical degradation and weather-related outages Storm hardening programs
<b>Sea levels</b>	Increased risk of flooding in coastal areas, especially for generating stations and substations, but also cable chambers	Increased weather-related outages (storm surge) Manage seasonal flooding
<b>Wind patterns</b>	Changes to dynamic line ratings, mechanical loads (due to wind), and wind generation	Location-specific changes to mechanical degradation
<b>Extreme hot/cold weather</b>	Extreme temperatures will increase overloading and put more stress on assets	More thermal deterioration
<b>Risk of bushfires</b>	Cracked/contaminated insulators and lightning surges can cause pole fires leading to large-scale bushfires	Bushfire as an impact of catastrophic asset failure (i.e. pole fire) Manage using lightning arresters, faster switching, and targeted maintenance (e.g. IR scan, insulator washing)

These effects will generally impact three areas of the utility’s asset management process:

1. Asset condition assessment and failure probability (e.g. faster degradation rates in changing climates, more operational stresses due to increased harmonics, transients, and short-circuit current, and the increase occurrence of short-duration overloading).
2. Impact assessment and risk calculation (e.g. high-impact, low-probability events, the dynamic value of energy for the grid and climate of the future, and changing load profiles).
3. Project scoping and comparison of projects/alternatives to address a broad range of outcomes (e.g. reinforcing poles, installing line surge arresters, and deferring asset sustainment when the usefulness of the line or station is uncertain).

Figure 3 illustrates changing risk and maintenance costs for items (1) and (2) above, accounting for faster equipment degradation, more operational stresses, increased overloading, increasing customer interruption costs, and high-impact, low-probability events.



**Figure 3: Changing Risk and Maintenance Costs for Different Scenarios**

Depending on the selected uncertainty, the effect on risk and maintenance costs will vary, and in some cases, the future risk may decrease. For example, microgrids and behind-the-meter generation would decrease customer impacts during a forced outage on the grid.

Evaluating future risk and mitigation strategies allows the asset manager to optimally allocate expenditures by reducing present-day and future risk costs. Options to mitigate risk include asset sustainment investments to reduce the probability of a forced outage, system upgrades to increase grid capacity, and other alternatives that reduce the impact of forced outages, such as installing lightning arresters or faster switches to mitigate the risk of pole fires. In instances when the future usefulness of a line or station is uncertain, it may be optimal to defer investments until future scenarios become more certain. Rigorous application of the risk-based asset management approach will allow the utility to optimize expenditures by minimizing the TCO for infrastructure while considering future uncertainties.

## 4. CONCLUSIONS

To prepare for future uncertainties, a consistent evaluation framework, such as the risk-based asset management approach presented in this paper, must be applied. This approach is especially useful for long-term planning exercises looking forward 10 to 25 years, as changes to future risk and maintenance costs become more significant for longer outlooks. The framework is robust enough such that it can be applied to an entire utility, local geographical areas, or larger regional transmission organizations.

Utilities should focus on the most likely areas of uncertainty depending on their unique operating environment. Targeted capital investment and maintenance should address the areas of greatest risk, considering the uncertainty of future scenarios along with present-day capacity upgrade and asset sustainment needs. The greatest impact on future risk and maintenance costs will occur due to faster equipment degradation, more operational stresses, increased overloading, increasing customer interruption costs, and high-impact, low-probability events. Certain areas of technological development such as microgrids, behind-the-meter generation, and peer-to-peer energy transactions will tend to decrease future asset risk and maintenance costs relative to the base case.

The degree of variation among future uncertainties highlights the need for improved forecasting and better end-of-life models for equipment based on loading. There is also a need to monetize the emission of SF6 gas in a manner similar to carbon dioxide emissions.

Risk mitigation strategies should be planned to address future uncertainties. Enhanced maintenance, strategic asset relocation, storm hardening, and bushfire mitigation are among the key strategies to reduce risk on the power grid. The systematic evaluation of risk mitigation strategies using a risk-based asset management approach allows for the optimal allocation of capital and maintenance expenditures.

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