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Risk assessment approaches to managing weather extremes in energy systems

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Risk Assessment Approaches to Managing Weather Extremes in Energy Systems

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Presentation Outline

- Possible Effects of Climate Change on Energy Systems
- Summary of Risk Assessment and Management Techniques
- Evaluation of Vulnerabilities of Energy System to Sustained Extreme Weather Conditions: A Risk Assessment Approach
- Conclusions

Effects of Climate Change on Energy Systems

- Concerns:
  - Degradation and/or high stresses resulting in failures
  - Performance of the operators
  - Significant increases in electricity use
  - Limited water supply
  - safe and sustained operability of energy systems
  - widespread losses in energy production

Effects of Climate Change on Energy Systems (Cont.)

- Energy systems are vulnerable to:
  - Sea-Level Rise
  - Extreme Drought
  - Flooding
  - Extreme Sustained Temperature
  - Fire
  - High Wind: Hurricane and Tornado
  - Warm Water
  - Ice Storms

Effects of Climate Change on Energy Systems (Cont.)

- Electric Grid: Ice Storms, hurricane, landslide
- Hydroelectric: Snowpack melting, drought
- All power plants: Water supply, warm air, high wind, flooding, rising water body levels, wildfire, human performance
- Renewable energy: changing cloud cover
- Biomass production: water supply

Definition of Risk

- **Risk** is a measure of the **potential loss** occurred due to natural or human activities
- Potential losses are the adverse consequences of such activities in form of adverse health effects, loss of property and production, and damage to environment.
- **Risk analysis** is the process of characterizing, managing and informing others about existence, nature, magnitude, prevalence, contributing factors, and uncertainties of the potential losses.

Categories of Risk Analysis

- ***Health risk analysis***
- ***Safety risk analysis***
- ***Security risk analysis***
- ***Financial/economic risk analysis***
- ***Environmental risk analysis***

Elements and Types of Risk Analysis

- Risk analysis attempts to measure the magnitude of a loss (consequences) associated with energy systems, including evaluation, risk reduction and control policies.
- There are three types of risk analysis: Quantitative, Qualitative and a Mix of the two
- There are three elements (constituents):
  - **Risk assessment**
  - **Risk management**
  - **Risk communication**

Risk Assessment

- Risk assessment is the process of providing answer to four basic questions:
  1. What can go wrong?
  2. How likely is it?
  3. What are the losses (consequences)?

Scenario	Likelihood	Damage
S_1	l_1	X_1
S_2	l_2	X_2
S_3	l_3	X_3
$\vdots$	$\vdots$	$\vdots$
S_N	l_N	X_N

$$R = \text{RISK} = \{\langle S_1, l_1, X_1 \rangle\}$$

Engineering Risk Assessment

- Mathematical representation of risk

$$\text{Risk}\left(\frac{\text{Consequence}}{\text{Unit of time or space}}\right) =$$

$$\text{Frequency}\left(\frac{\text{Event}}{\text{Unit of time or space}}\right) \times \text{Magnitude}\left(\frac{\text{Consequence}}{\text{Event}}\right)$$

- One simple widely used model of risk value is ***linear expectation*** of the magnitude of outcome method:

$$R = \sum_i f_i \, c_i$$

Scenario Development

- Involves combination of failure events that lead to the losses (consequences)
- Failure events may be caused by extreme weather conditions leading to for Example:
  - Reduction in strength or endurance of energy system components
  - Changes in material properties
  - Stress or damage due to high temperature or pressure
  - Penetration or distortion by external objects or forces

Frequency and Consequence Estimation

- Frequency and probability estimation of events and scenarios are probabilistic in Nature
- Require engineering and reliability assessment
- Consequences are estimated by engineering analysis, exposure-consequence models, etc.

Risk Management

- Continually assesses the risks (what could go wrong?)
- Decides which risks are significant to deal with
- Employs strategies to avert, control or minimize risks
- Continually assesses effectiveness of the strategies and revise them, if needed

Risk Communication

- Based on the results of risk assessment and management exchange information with the stakeholders about:
  - The nature of the risk
  - The nature of the benefits
  - Uncertainties in risk assessment
  - Risk management options

Risk Margin Assessment

- Risk Margin assessments avoids the need to estimate the extreme weather hazard analysis (i.e., frequency of occurrence)
- Calculates the margins built into the energy system as a whole, as well a its components and structures to withstand extreme weather conditions
- Hazard analysis, especially in case of global warming, is controversial and involves high degree of uncertainties

How Margins are Estimated?

- Sometimes used in Seismic Risk Assessment by the Nuclear Power Industry
- Median Margin (MM) is calculated from engineering analysis (Finite Element, Degradation Analysis, Accelerated Failure Analysis, Engineering Judgment, etc.) used to estimate the safety factors inherent in the design of buildings, structures, and components of the energy systems as exposed to weather-induced conditions (stresses)

How is Safety Margin Expressed?

- The median margin above the sustained weather conditions is estimated including inherent uncertainty (U) and variability (R) in the margin estimation
- A commonly used margin of structure or a component, is the High Confidence Low Probability Failure (HCLPF) expressed as:

$$HCLPF = MM * \exp(-1.65(R + U))$$

Total Energy System Risk Margin

- All scenarios leading to economic losses or unsafe conditions, their corresponding HCLPF values, and the HCLPF of the whole energy system / facility to be estimated from the Min-Max approach
- Mathematically, the probability of failure, P_f, may be determined from the two-parameter lognormal distribution

$$P_f = \Phi\left(\frac{\ln HCLPF - \ln MM}{\left(R^2 + U^2\right)^{1/2}}\right)$$

Conclusions

- Global environmental changes are of much concern
- Certain sustained weather conditions may results from such global changes
- Estimation of the magnitude of the resulting weather-related conditions and frequency of hazards are difficult to estimate and subject to substantial uncertainties

Conclusions (Cont.)

- With reasonable confidence one may assess the margin built into specific energy systems to withstand failures in structures and components induced by the harsh conditions imposed by extreme sustained weather conditions
- The proposed probabilistic risk margins may be used as the figure-of-merit metrics to assess the robustness and resilience of the energy systems to potential global weather phenomena and change events