

# Medium Voltage Underground Cable System Reliability

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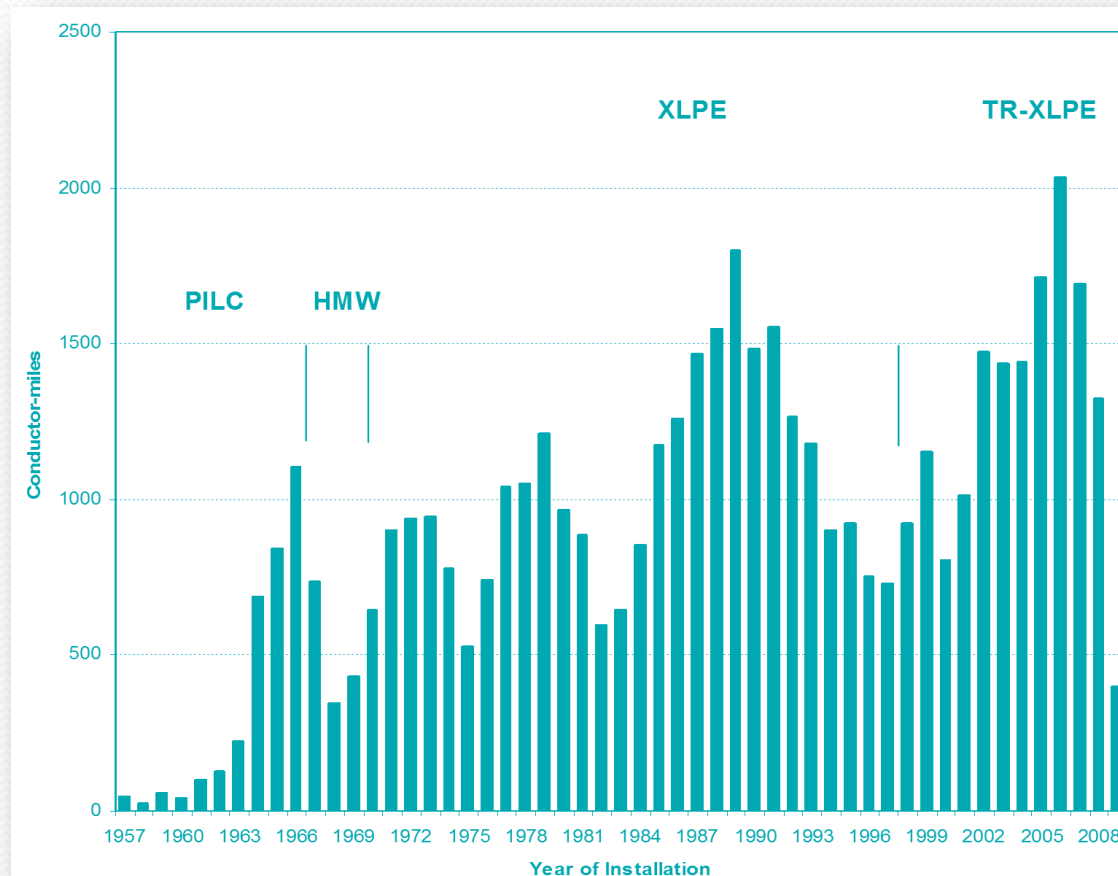
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# Introduction

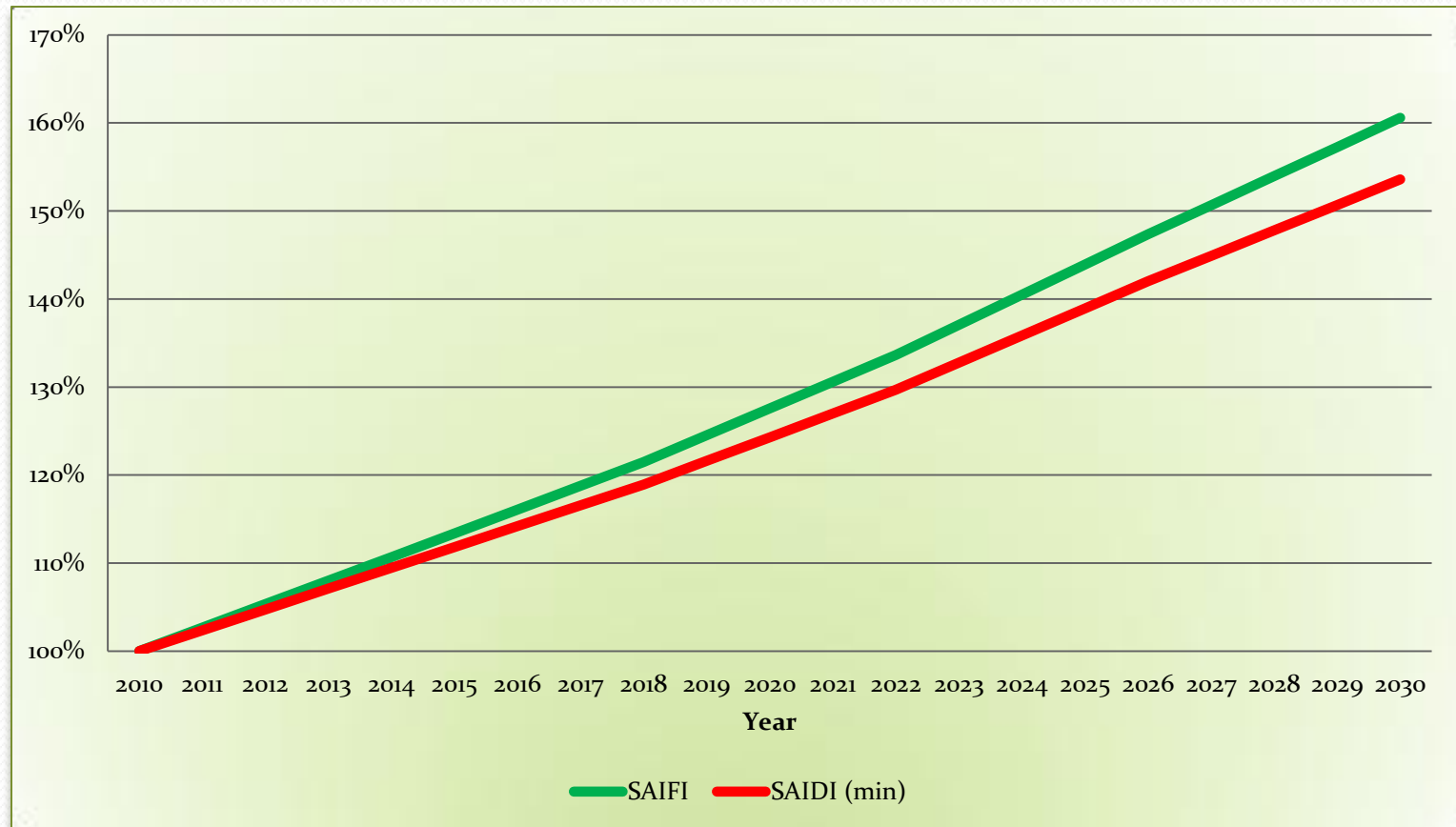
- Many utilities have aging underground cable systems that are failing at an increasing rate.
- Aggressive underground replacement programs are often difficult to justify since it is difficult to know whether any specific cable section will fail in the near future.



# Example of Cable Age



# System Reliability Trend



# Presentation Overview

- This presentation demonstrates how a large US utility justified an aggressive cable replacement program in its current rate case.
  - Cable failure rate model;
  - System reliability models;
  - The expected reliability over a twenty year period for various replacement scenarios;
  - The economics of cable replacement.

# Questions to be answered

- **How to assess the system impact from circuit studies?**
- **How to simulate the reliability impact of proactive underground cable replacement?**
- **How to justify the program?**



# Representative Circuits

- It is neither necessary nor desirable to model and study all circuits for any large system.
- It is nontrivial to select one or few typical circuits to represent the entire system.
- The representative circuit approach applies a divide-and-conquer strategy to identify a set of circuits to present the system.

# Cluster Analysis - Overview

- Group the circuits, based on their features, into a number of subsets.
- Different system characteristics are represented by different subsets and each subset is represented by a typical circuit.
- Less diversity of circuit characteristics enables a better feature representation.

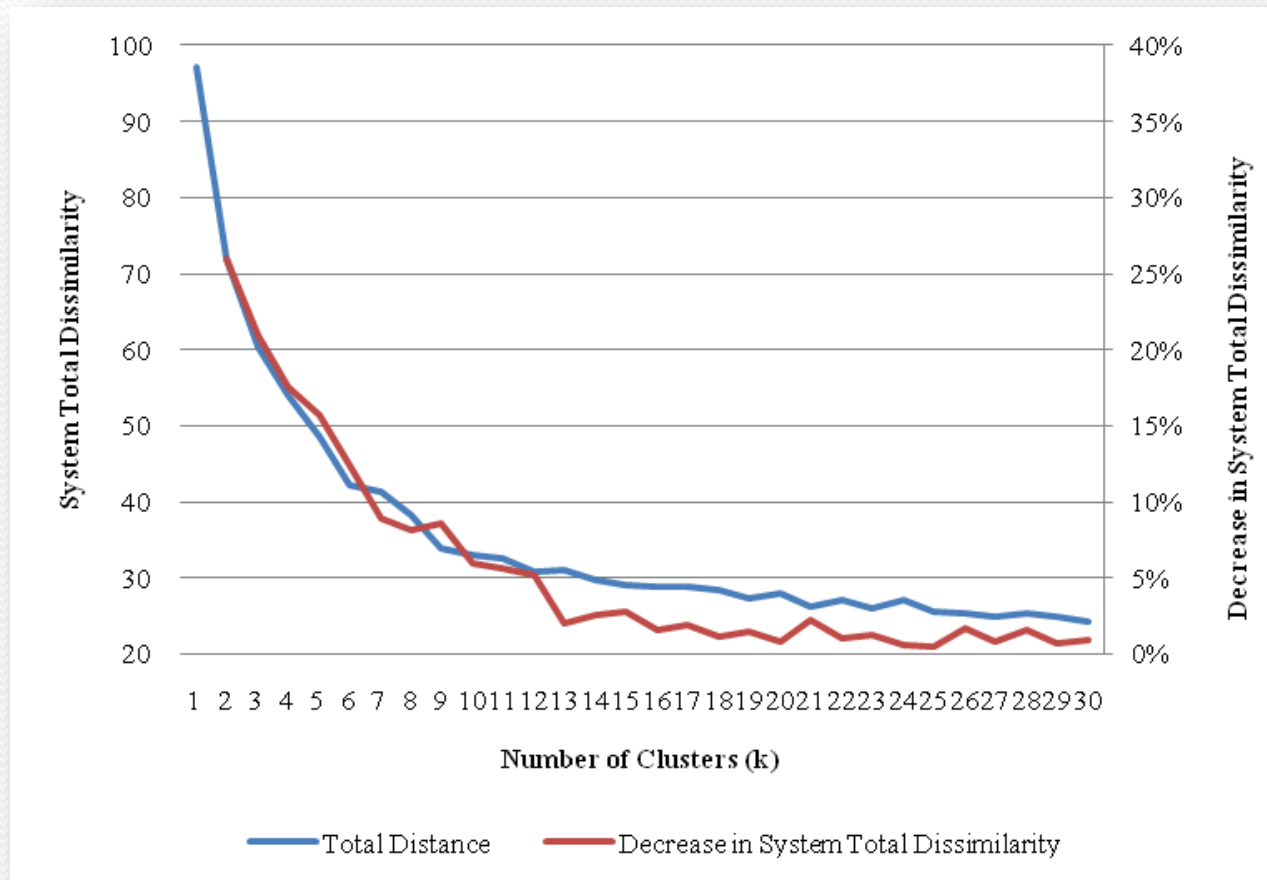
# Cluster Analysis – Circuit Similarity

- Not all the circuit features are relative.
- Not all the relevant features are equally important.
- Engineering judgment or statistical methods such as correlation analysis or regression analysis.

# Cluster Analysis – Number of Subsets

- More groups lead to better representativeness, but more effort and cost.
- Our previous studies show that 25 is a reasonable choice, with the trade-off between study accuracy and effort, for a population of thousands of circuits.

# Cluster Number Determination

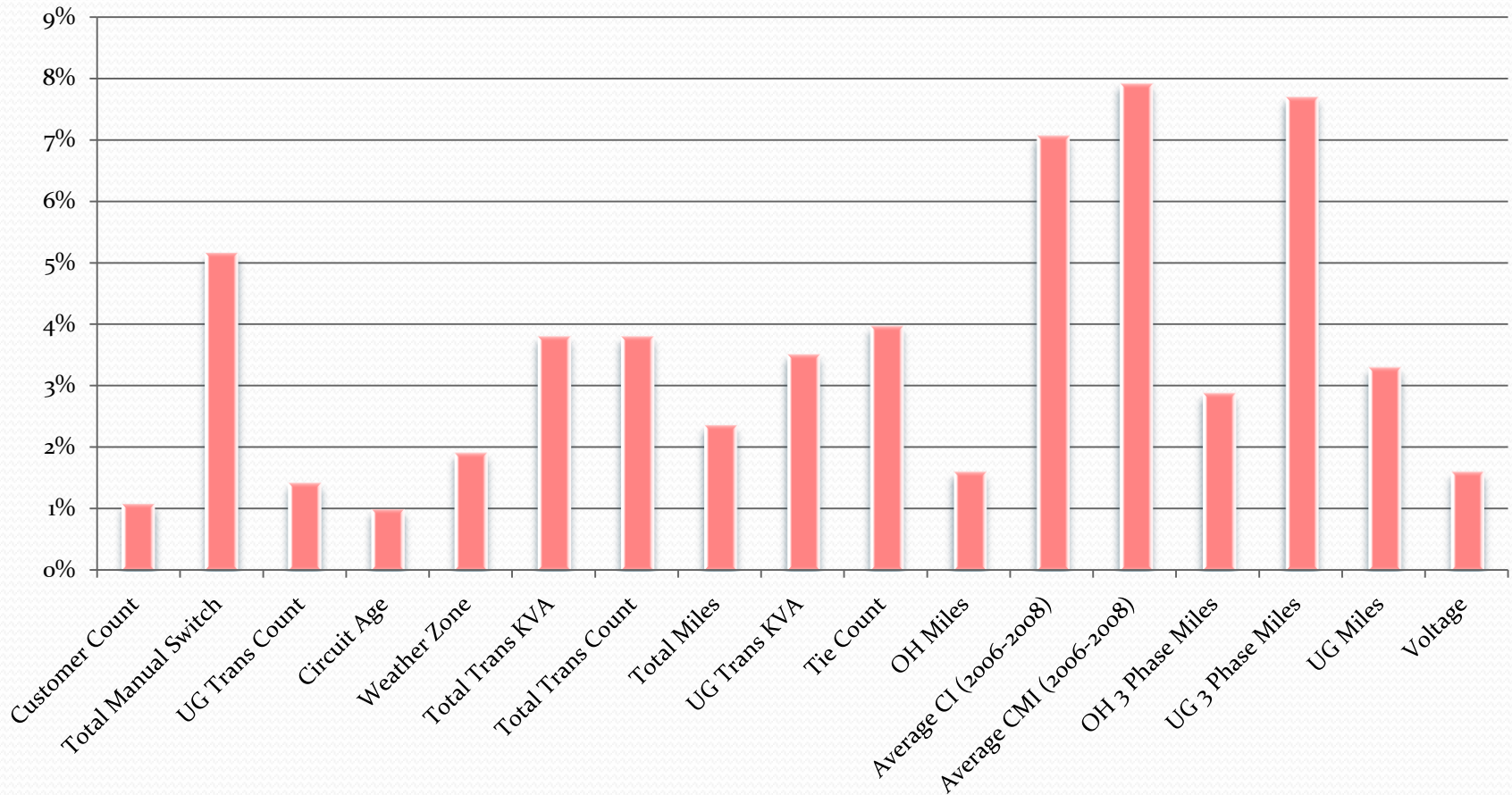


# System Extrapolation

- Various weighting schemes: the most straightforward extrapolation approach is to weigh the reliability impact derived from a representative circuit by the number of circuits within its cluster.



# Extrapolation



# Questions to be answered

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# Reliability Study Approach

- Develop models to accurately reflect the historical performance of actual systems (circuits or group of circuits).
- Assess the reliability of the existing system without any modifications.
- Assess the impact of underground cable aging, proactive replacement, different reliability improvement options via various simulation scenarios.

# Reliability Indices

- SAIFI: System Average Interruption Frequency Index:

$$SAIFI = \frac{\text{Total Number of Customer Interruption}}{\text{Total Number of Customers Served}}$$

- SAIDI: System Average Interruption Duration Index:

$$SAIDI = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Served}}$$

# Model Development

- Predictive Reliability Model:
  - Connectivity model includes the distribution system configuration, protective and switching devices, customers, and loads.
- The ages of underground cable are assigned to different sections.
- Distribution system operation practices such as over-current protection scheme and reclosing scheme are set or assumed.

# Calibration

- Circuit reliability parameters such as failure rates and repair time are adjusted to ensure the developed circuit model reflect the historical reliability of the system it represents.

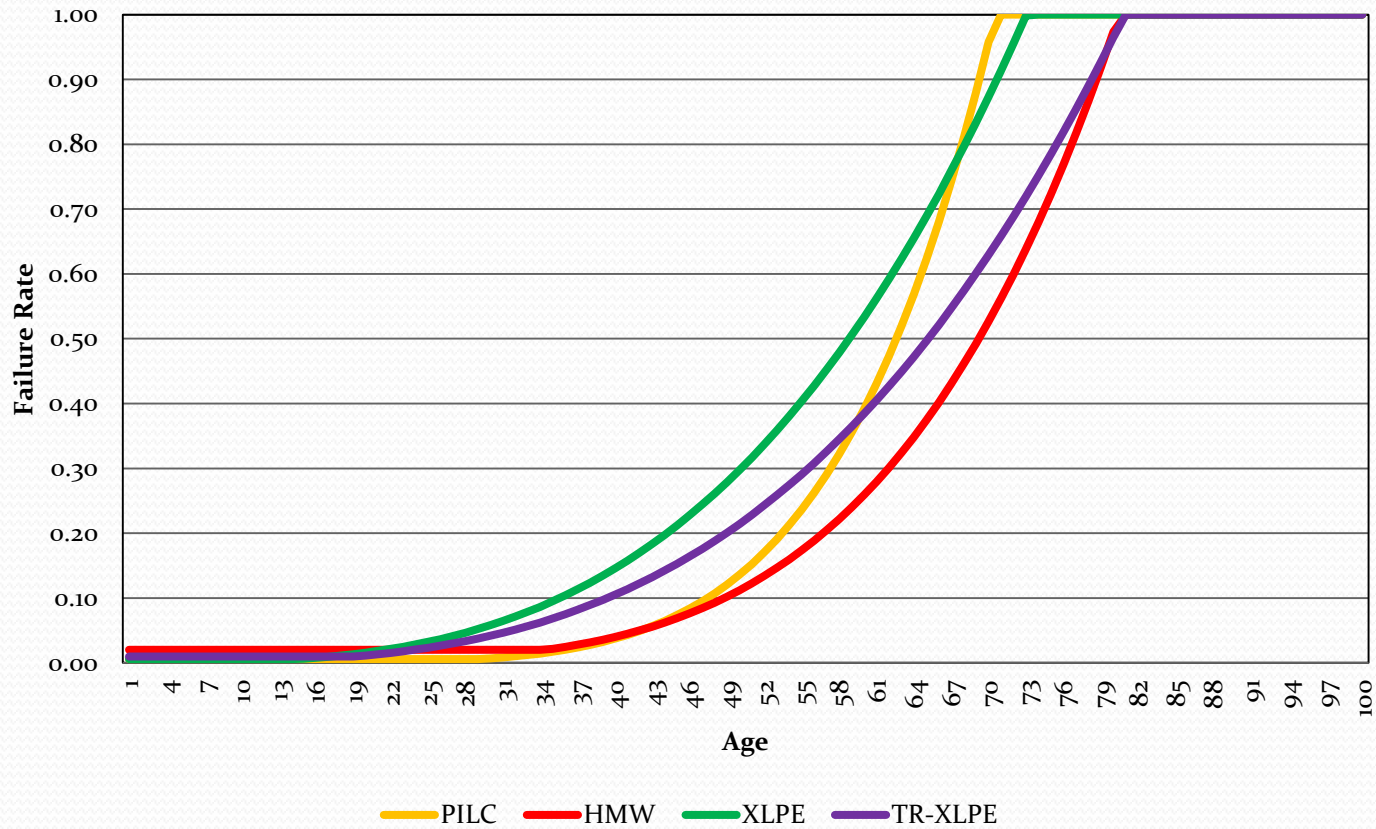
	Calibrated SAIFI	Difference (%)	Calibrated SAIDI	Difference (%)
All Circuit (System)	1.064	-0.40%	2.284	0.18%
Worst Circuit Rehabilitation Group	1.792	-0.56%	3.475	0.04%

# Simulation Approach

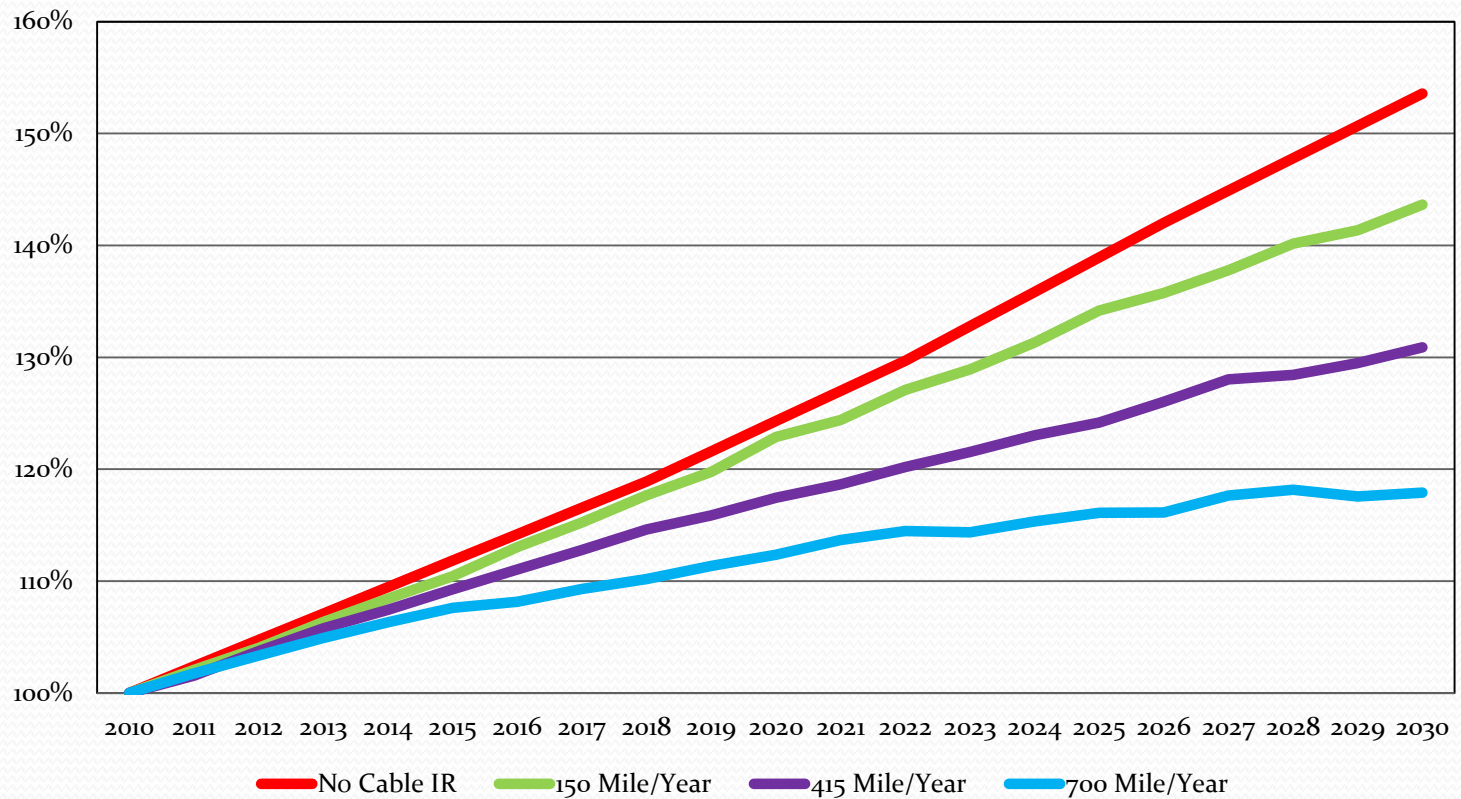
- 20-year simulation
  - Cable age and failure rate update
  - Cable failure simulation
  - Regular underground cable replacement
  - Cable replacement selection
  - Proactive underground cable replacement
- Three scenarios
  - 150 miles/year
  - 415 miles/year
  - 700 miles/year



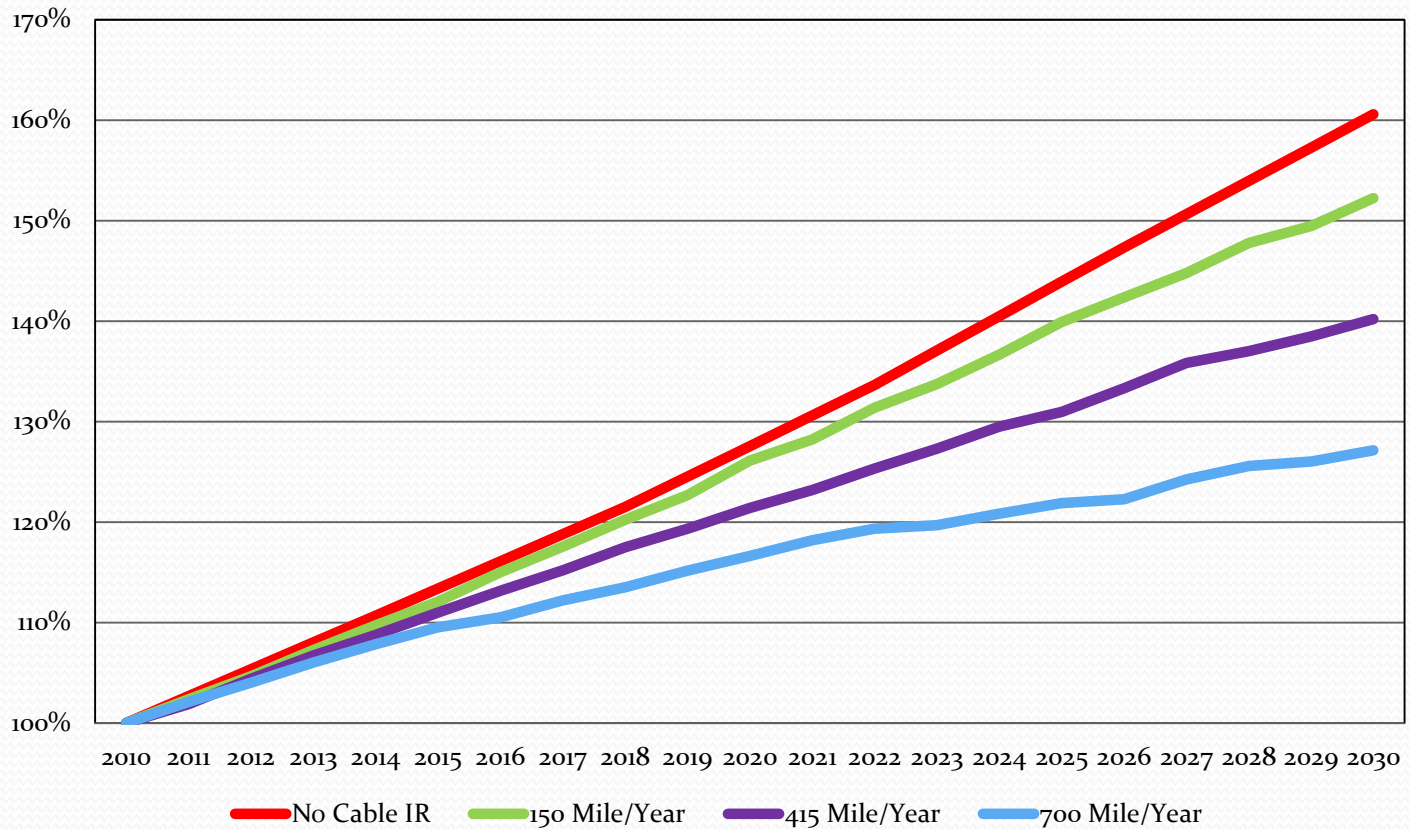
# Underground Cable Failure Rate



# SAIDI Comparison



# SAIFI Comparison



# Other Reliability Improvements

- Aging Related
  - Underground Switches
  - Distribution Transformer
- Non-Aging Related
  - Distribution Automation
  - Lateral Fuses
  - Reclosers
  - Sectionalizing

# Questions to be answered

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- **How to justify the program?**



# Cost-Benefit Analysis

- Benefit: Reliability improvement such as SAIDI reduction.
- Cost: Time value of money - the value of money figuring in a given amount of interest earned over a given amount of time.

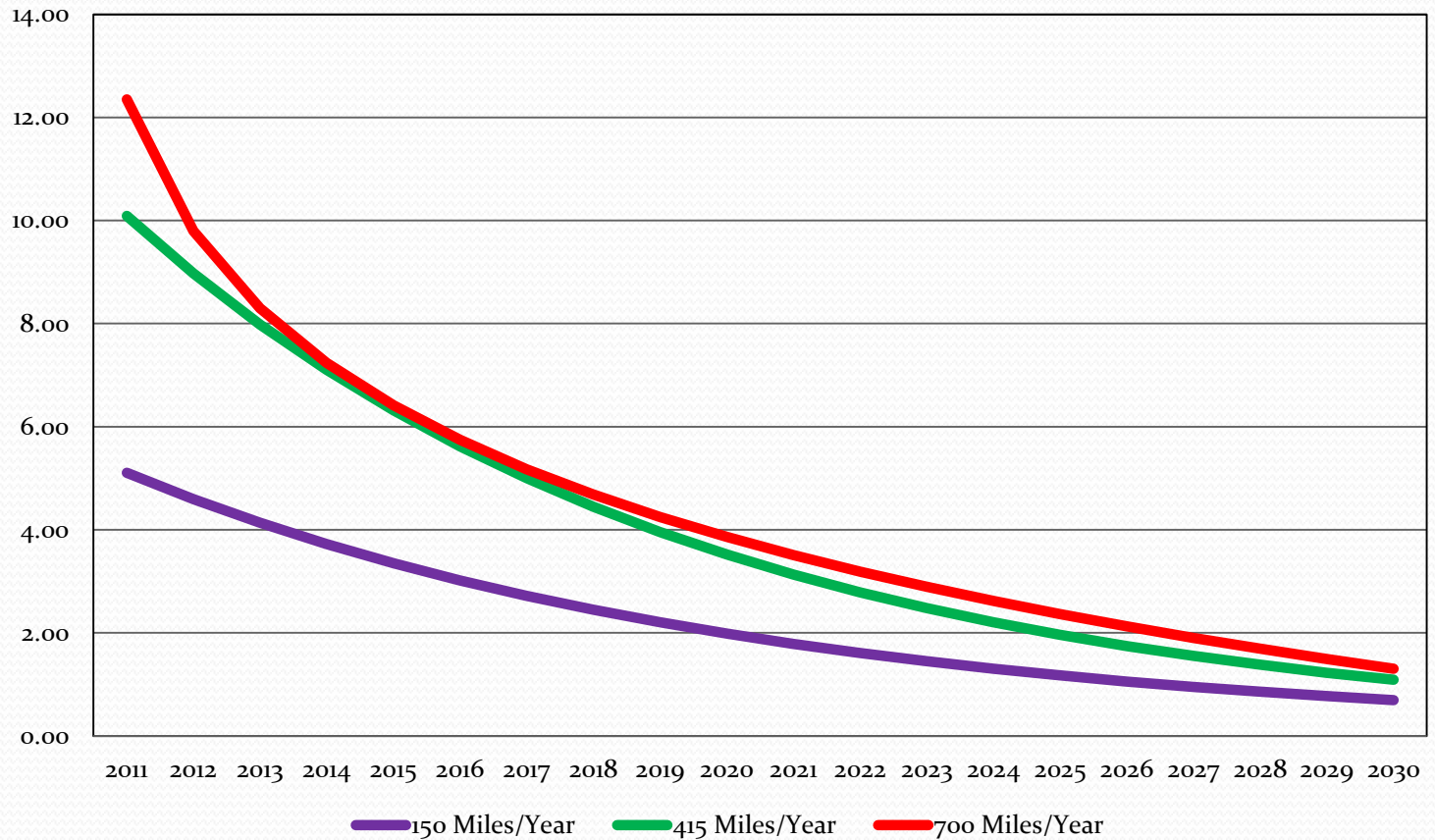
## A Cable Replacement Example:

Replacement cost: \$10,000; discount rate: 10%

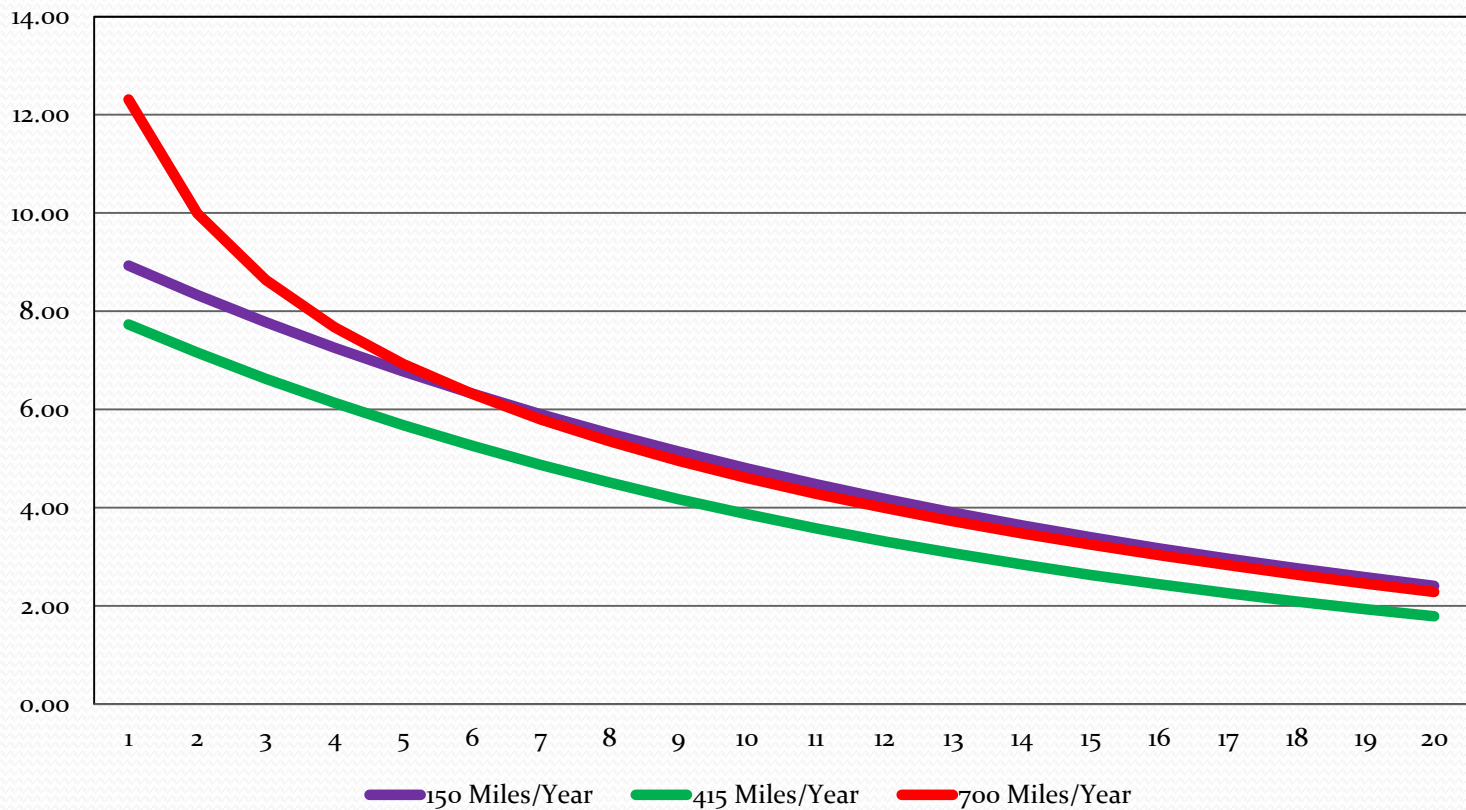
One year earlier:  $\$10,000 - \$10,000/(1+0.1) = \$909.09$

Three years earlier:  $\$10,000 - \$10,000/(1+0.1)^3 = \$2,486.85$

# \$/CMI reduction – Cable Only



# \$/CMI reduction – Integrated Case



# Conclusions

- Aging cable will result in increased SAIDI and SAIDI of about 50% over the next twenty years.
- Proactive replacement efforts should be integrated with the other reliability improvement programs that focuses on circuits with relatively poor reliability and equity of service among customers.
- Strategy may change over years.