# Sparing Strategies for Power Transformers

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# Sparing Strategies for Power Transformers

## Strategy Development

- Data Requirements:
  - List of in-service power transformers and their parameters.
  - Inventory of available spare transformers, their locations, and condition.
- Considerations for Evaluating Sparing Needs and Risks:
  - Failure history for specific populations of transformers.
  - Number of transformers in each population.
  - Lead time for replacement.
- Example/Case Study

# Sparing Strategies for Power Transformers

## Data Requirements

- A list of in-service power transformers and available spares must be developed. Can be downloaded from maintenance software.

- The list must contain the necessary parameters to match spares with in-service units, including but not limited to:
  - KVA Rating
  - # of Phases
  - Voltage Ratings
  - Connection
  - Cooling Class & Temperature Rise
  - Impedance
  - LTC vs. non-LTC
  - Location
  - Vintage and Condition

- The list must be maintained up-to-date.

# Sparing Strategies for Power Transformers

## Data Requirements

- Available spares must be matched with corresponding in-service transformers to identify gaps where additional spares are needed.

- Levels of Matching:
  - Exact match
  - Close match; examples:
    - Impedance mismatch
    - KVA mismatch
    - LTC mismatch
  - No match – spare needs to be ordered

- Mobile transformers must be available as temporary spares in the event of a failure, if system planning cannot divert power to other units, until a permanent replacement can be installed.

# Sparing Strategies for Power Transformers

## Additional Considerations

- Locations of Spares:
  - In Service Spare – a unit that can carry the full load of another unit that fails. Double-redundant. Immediate replacement or mobile transformer not required.
  - Out of Service Spare:
    - Local - in the same station. Minimal or no transportation or assembly required for installation.
    - Remote – in another location. Transportation and possible disassembly and oil handling required for installation. Transportation plans should be developed for large units requiring heavy haul vehicles and permits.
    - Remote – condition unknown, untested, parts missing.

- Outside Sources:
  - Other Utilities
  - Used Equipment Brokers
  - Equipment Sparing Programs - mutual transformer sharing agreements to purchase spare units from other member utilities if qualifying events exhaust in-house spares in specific voltage classes. Step/Restore. Exact matching may not be achievable and must be evaluated.

# Sparing Strategies for Power Transformers

## Risk Analysis Case Study

To determine the risk of being without a spare following a failure that occurred in 2019, DLC reviewed the historical failure data for the specific population of transformers and performed a statistical analysis as follows:

### Population Statistics

- 33 transformers of varying vintages from 1964 thru 2011.
- Average vintage = 1993.
- Average age at the time of the failure = (2019 – 1993) = 26 years.

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## Risk Analysis Case Study

Population Failure History (1999 – 2019)

| Location | Year Failed | Year Installed | Service Age at Failure |
|---|---|---|---|
| Bank #1 | 2019 | 1970 | 49 years |
| Bank #2 | 2017 | 1979 | 38 " |
| Bank #3 | 2008 | 1972 | 36 " |
| Bank #4 | 2007 | 1984 | 23 " |
| Bank #5 | 2006 | 1987 | 19 " |
| Bank #6 | 2004 | 1970 | 34 " |
| Bank #7 | 10/1999 | 1961 | 38 " |
| Bank #8 | 05/1999 | 1976 | 23 " |

Average age at time of failure = 32.5 years; Std. Dev. = 10 years

Times between failures = 2, 9, 1, 1, 2, 4.5 & 0.5 years

Average time between failures = (2+9+1+1+2+4.5+0.5) / 7 = 2.9 years

Standard deviation of time between failures = 3.0 years

On average 1 spare of this type will be needed every 2.9 years.

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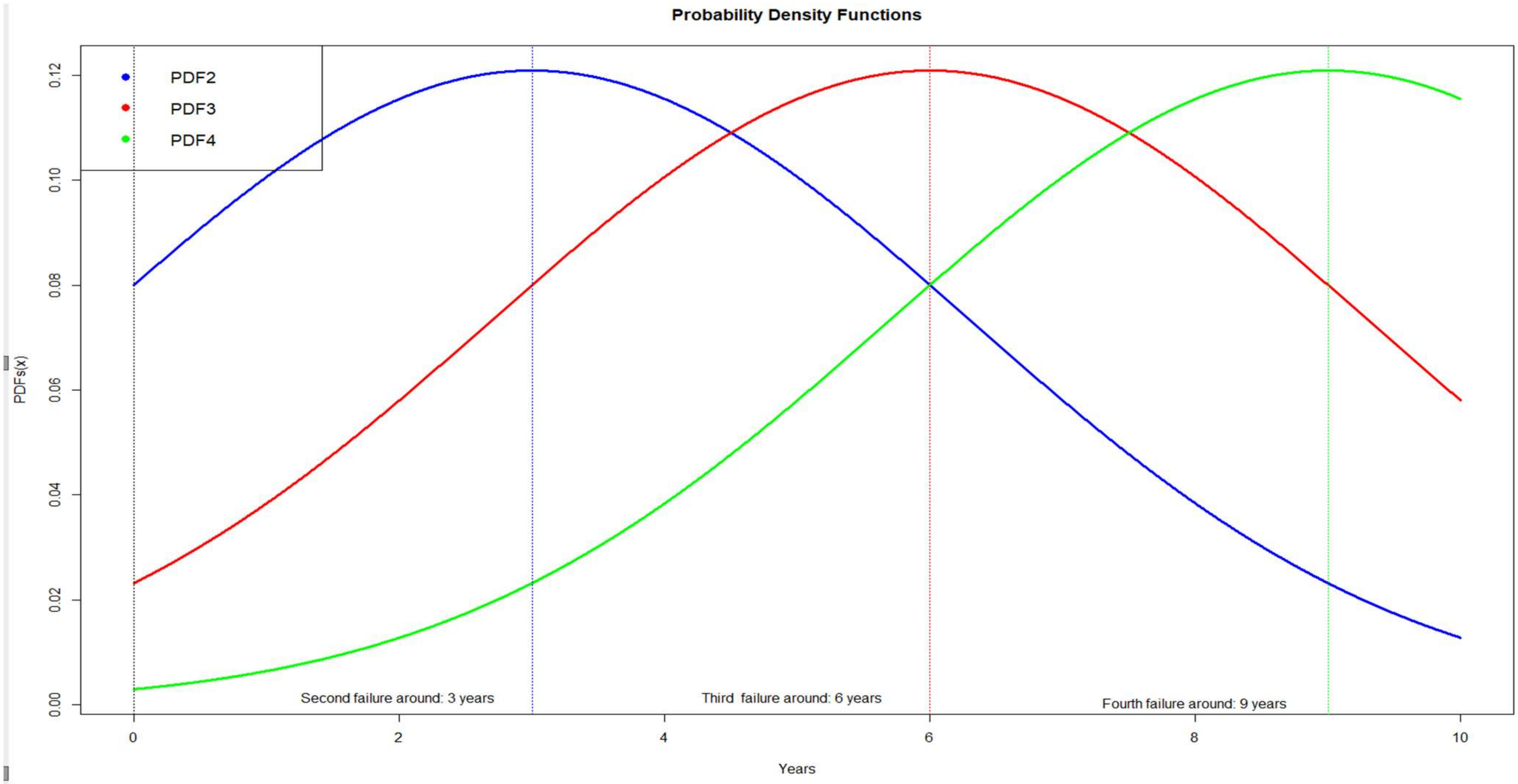
## Risk Analysis Case Study

- Using the average and the standard deviation of the time between failures the Probability Distributions of future failures were plotted as follows:



# Sparing Strategies for Power Transformers

## Risk Analysis Case Study

Single (1) Spare Scenario – One transformer in the population fails and is replaced by a lone spare unit, placing us at risk for additional failures, without a spare, during the 1-year lead time that it took to procure and install a replacement spare at that time.

The cumulative risk of additional failures during the 1-year lead time was calculated by integrating the above Probability Distributions from the date of the failure, at time = 0, to a point 1 year after the failure.

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## Risk Analysis Case Study

The cumulative probabilities of additional failures during the 1-year lead time were calculated as follows:

The probability of a 2nd failure = P(-0.63σ) – P(-0.97σ) = 0.264 – 0.166 = 0.098

The probability of a 3rd failure = P(-1.60σ) – P(-1.93σ) = 0.055 – 0.027 = 0.028

The probability of a 4th failure = P(-2.57σ) – P(-2.90σ) = 0.005 – 0.002 = 0.003

The sum of the above probabilities = 0.129

Conclusion: For the Single-Spare Scenario, the risk of additional failures, without a spare, during the 1-year lead time = 12.9%

Recommendations:

- If a loan spare is used to replace a failed unit, a replacement spare should be ordered as soon as possible.
- To further reduce the risk of not having a spare available in the event of a failure of a lone spare, a 2nd spare of this type should be ordered.

# Sparing Strategies for Power Transformers

## Risk Analysis Case Study

Two (2) Spare Scenario - One transformer fails and is replaced by one spare unit, and a 2nd unit also fails at the same time and is replaced by the 2nd spare, placing us at risk for additional failures, without a spare, during the 1-year lead time that it takes to procure replacement spares. The cumulative risk of additional failures during the 1-year lead time was re-calculated as described above:

The probability of a 3rd failure = P(-1.60σ) – P(-1.93σ) = 0.055 – 0.027 = 0.028

The probability of a 4th failure = P(-2.57σ) – P(-2.90σ) = 0.005 – 0.002 = 0.003

The sum of the above probabilities = 0.031

Conclusions:

- For the 2-Spare Scenario, the risk of additional failures, without a spare, during the 1-year lead time = 3.1%
- Having a 2nd spare available reduces the risk of additional failures from 12.9% to 3.1%, a 9.8% risk reduction.

Risk Analysis Case Study

## Further Recommendations:

- This analysis should be performed on other populations of transformers for the following reasons:
  - Failure rates may vary from one populations to another.
  - Failure rates will vary in proportion to the number of units in the population.
- This analysis should be updated each time that a failure occurs.
- This analysis should be updated if the lead time for replacement changes.

## Bibliography

[1] Bartley, William H., P.E., "Analysis of Transformer Failures", International Association of Engineering Insurers, 36th Annual Conference, Stockholm, 2003.

[2] Bartley, William H., P.E., "Failure History of Transformers – Theoretical Projections for Random Variables", $TJH_2B$, Tech Con, 2001

Questions / Discussion