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Electrical Substation Configuration Effect on Substation Reliability

Idaho National Laboratory

Motivation and Scope

- Institute of Electrical and Electronics Engineers (IEEE) recommends traditional probabilistic risk analysis (**PRA**) based on availability of individual components for designing reliable industrial and commercial power systems [1]
- PRA based studies only done on differences in configuration- no variation in **number of inputs/circuits**.

Legend: o Previous Work [2] x New Work

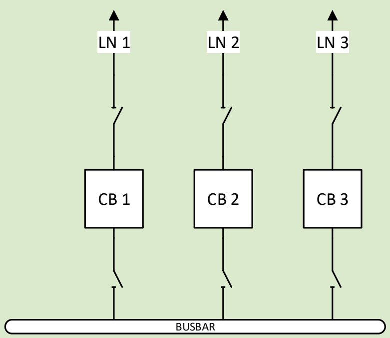
Configuration \ No. Lines	1	2	3	4	5	6	7	8
Single Bus	X	X	X	O	X	X	X	X
Breaker and a Half	X	X	X	O	X	X	X	X
Ring	X	X	X	O	X	X	X	X
Main and Transfer	X	X	X	O	X	X	X	X
Double Breaker- Double Bus	X	X	X	O	X	X	X	X

Methodology

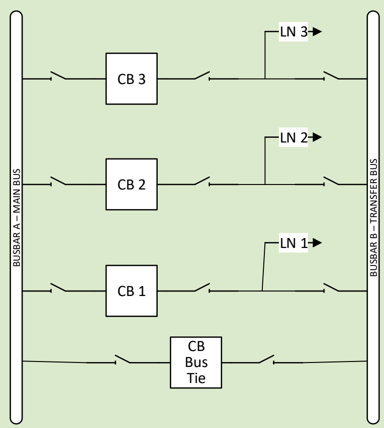
1. Obtain bus configuration
   - One line diagram of bus
2. Define failure criteria
   - Criteria that constitutes a failed bus
3. Define failure states and conditions
   - Detail combination of breakers, control panels, and busbars required to meet the failure criteria
4. Create logic statements and fault trees
   - From failure states
5. Evaluate and rank results of logic model
   - Failure probability and unavailability

Bus Configurations Considered

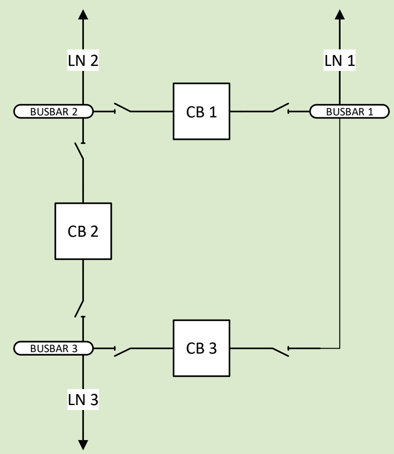
Single Bus



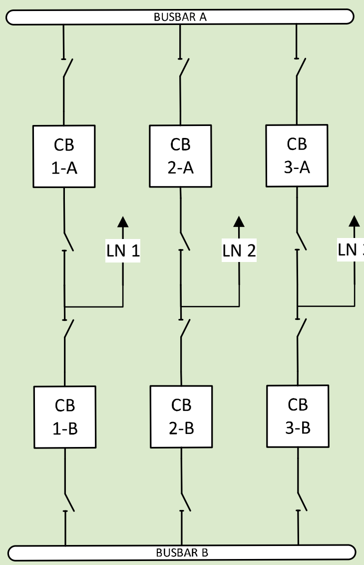
Main and Transfer



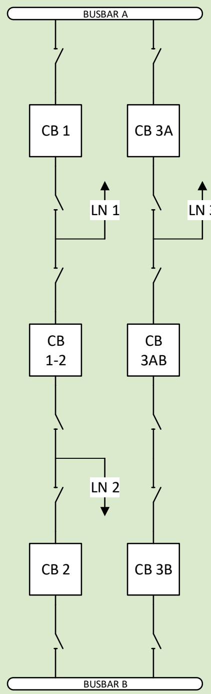
Ring Bus



Double Breaker/ Double Bus

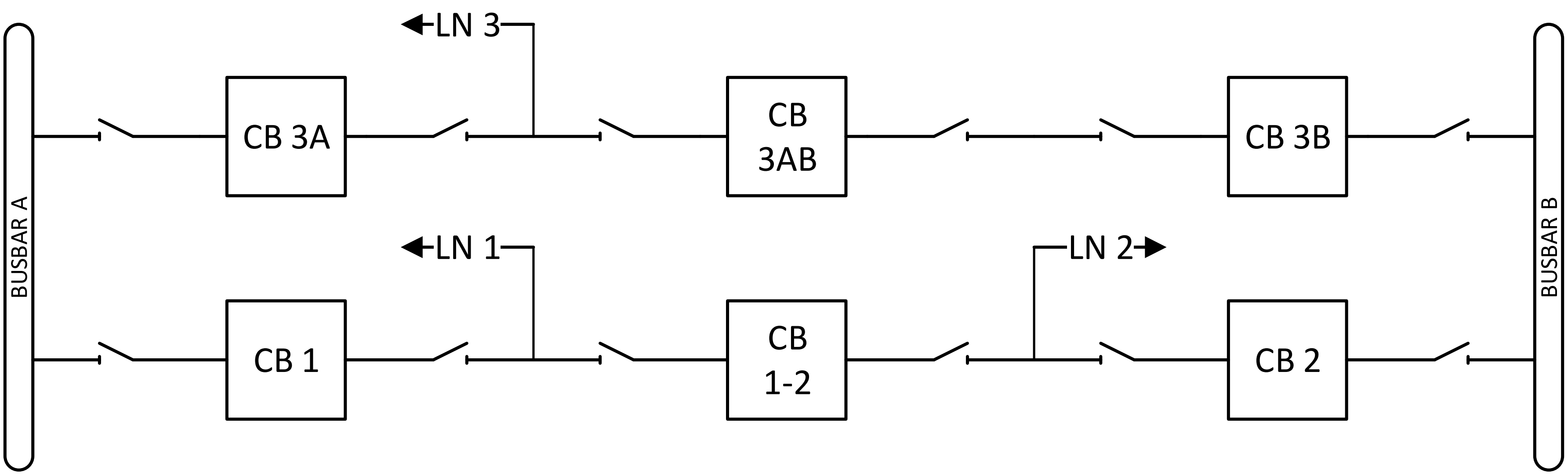


Breaker and a Half



Bus Configuration

Breaker and a Half, three lines



*Isolation switches not considered

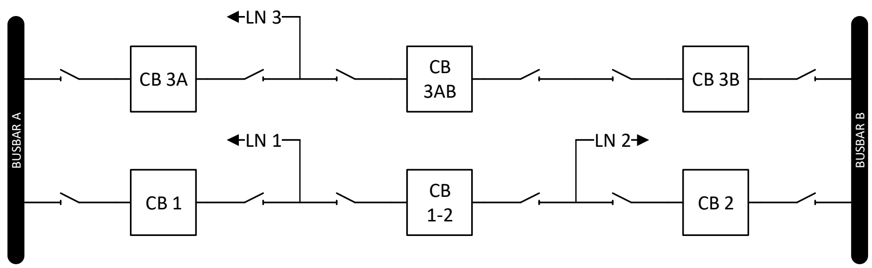
Failure Criteria

Bus cannot transmit any electrical signal

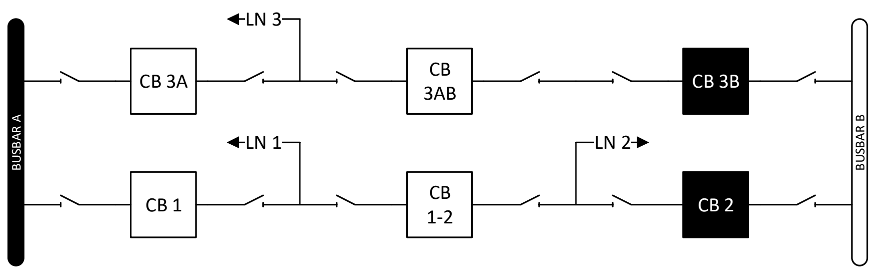
* Consistent for all substation configurations

Failure States

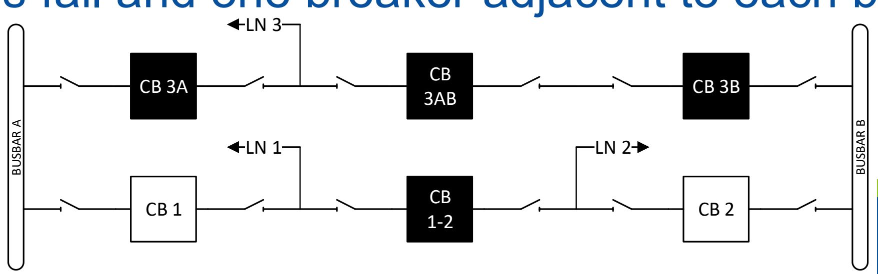
1. Both busbars fail



2. Bus fault with failed associated circuit breakers

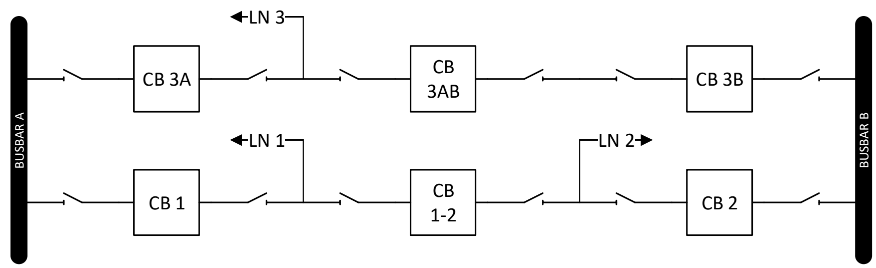


3. All middle breakers fail and one breaker adjacent to each busbar fails.



Failure States

1. Both busbars fail



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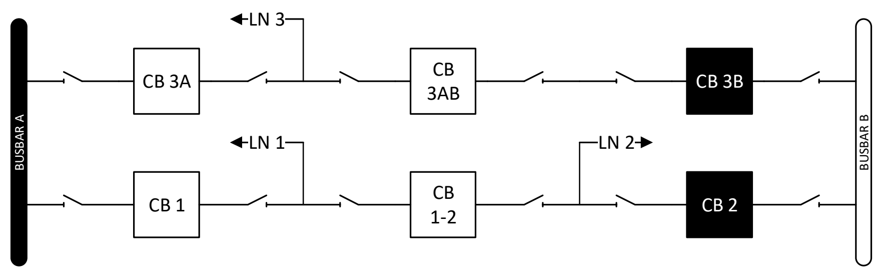
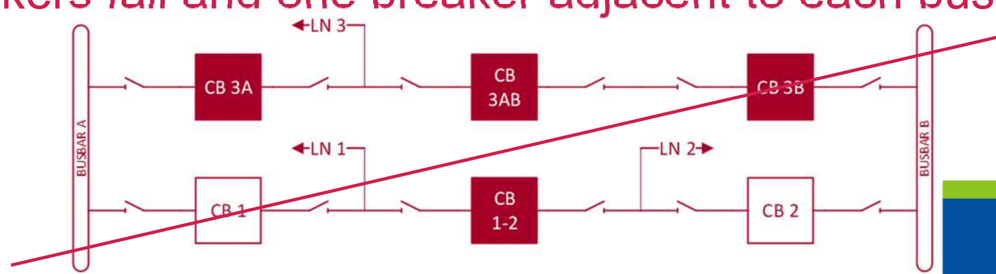
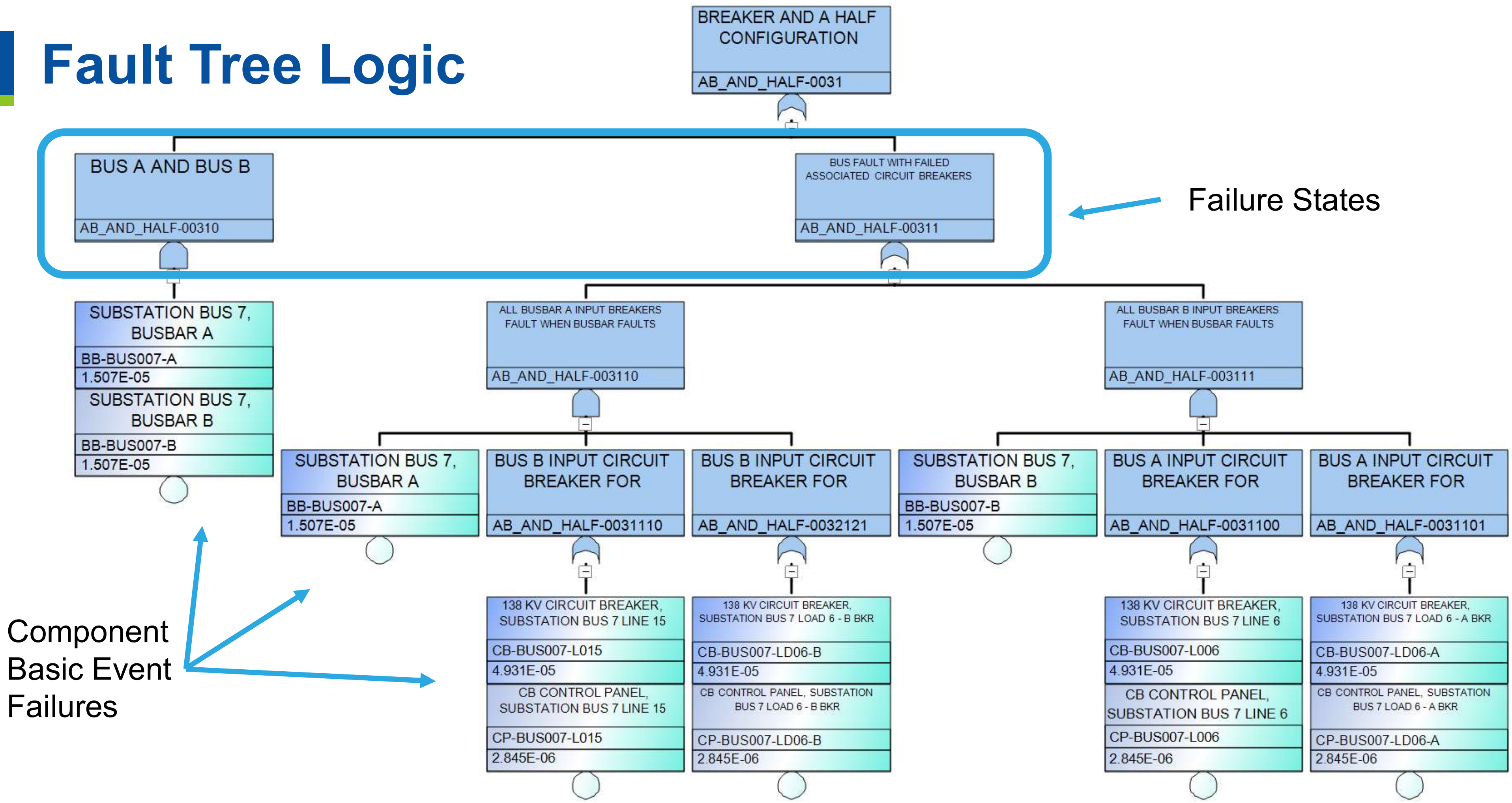


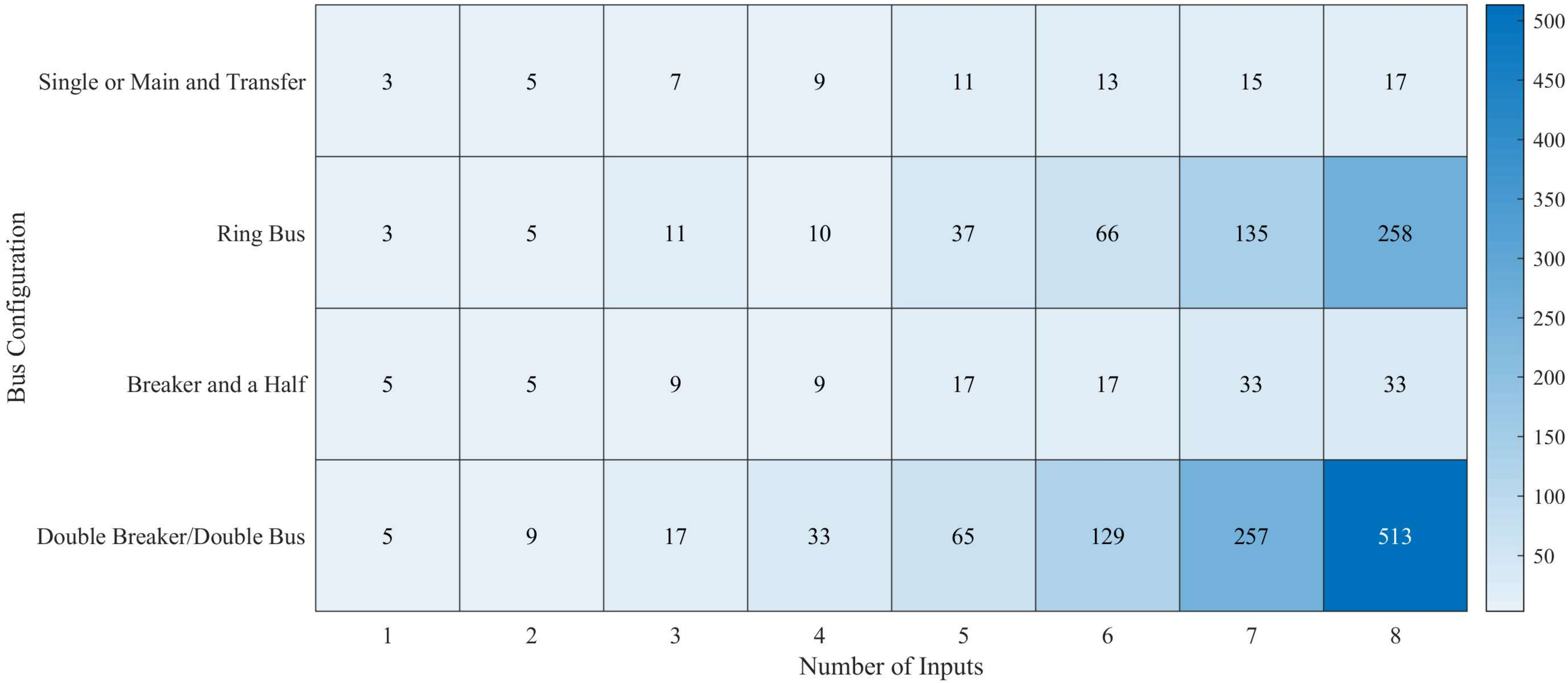
3. ~~All middle breakers fail and one breaker adjacent to each busbar fails.~~



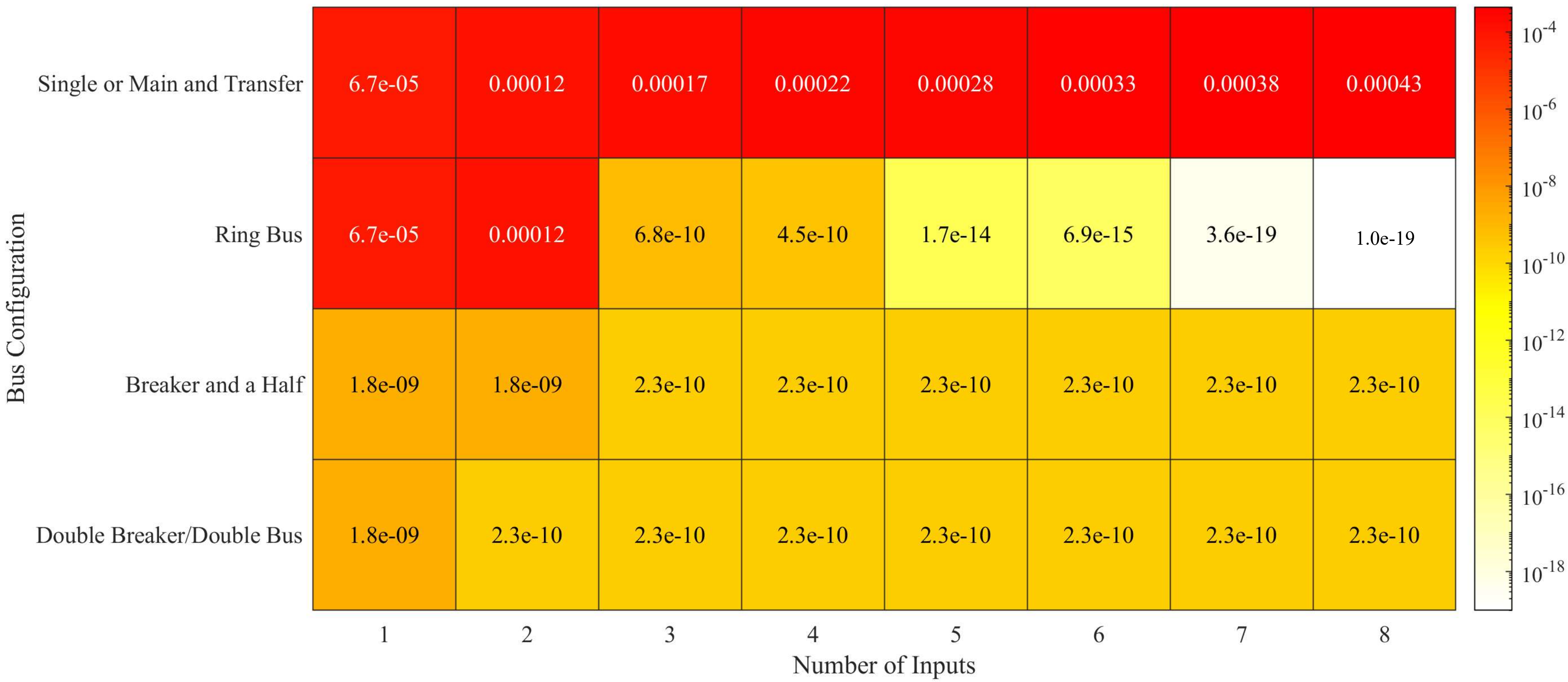
Fault Tree Logic



Cut Set Results

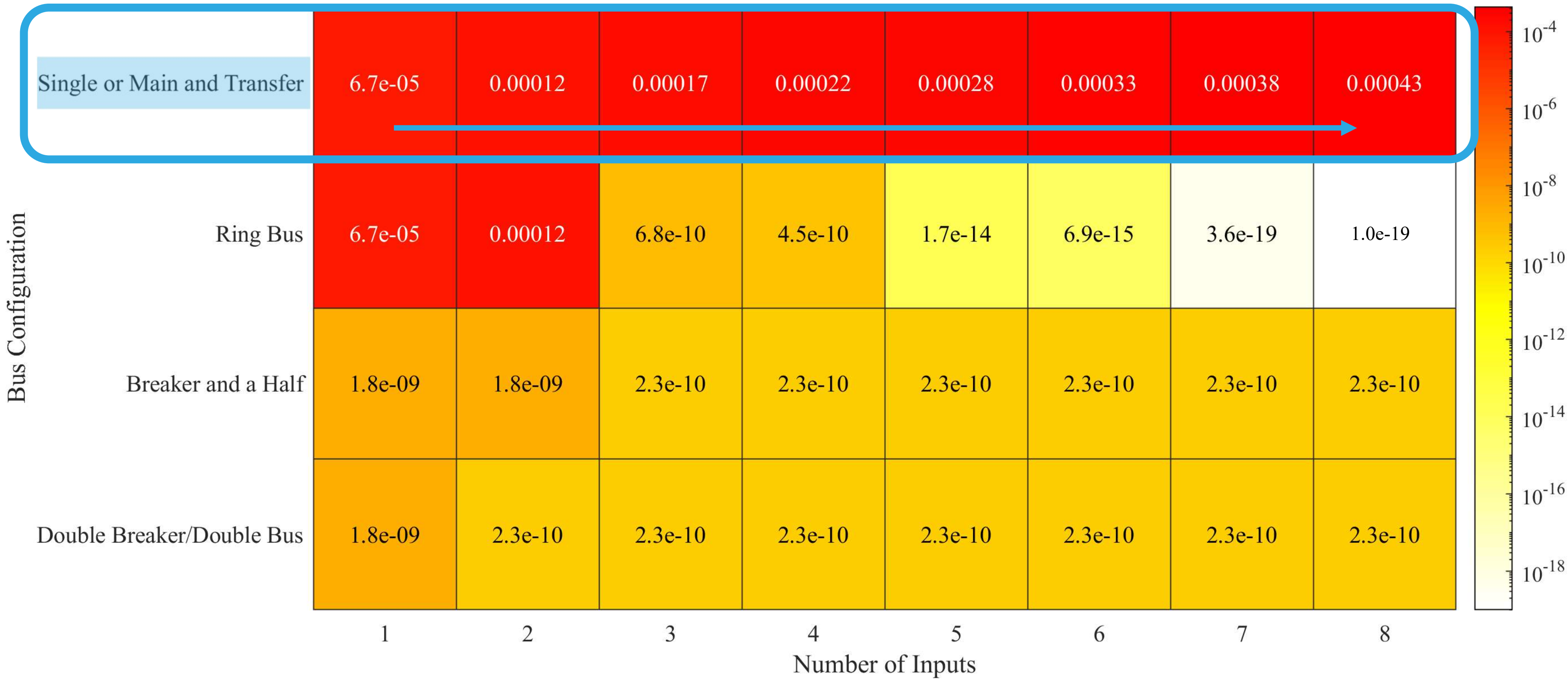


Failure Rate Results



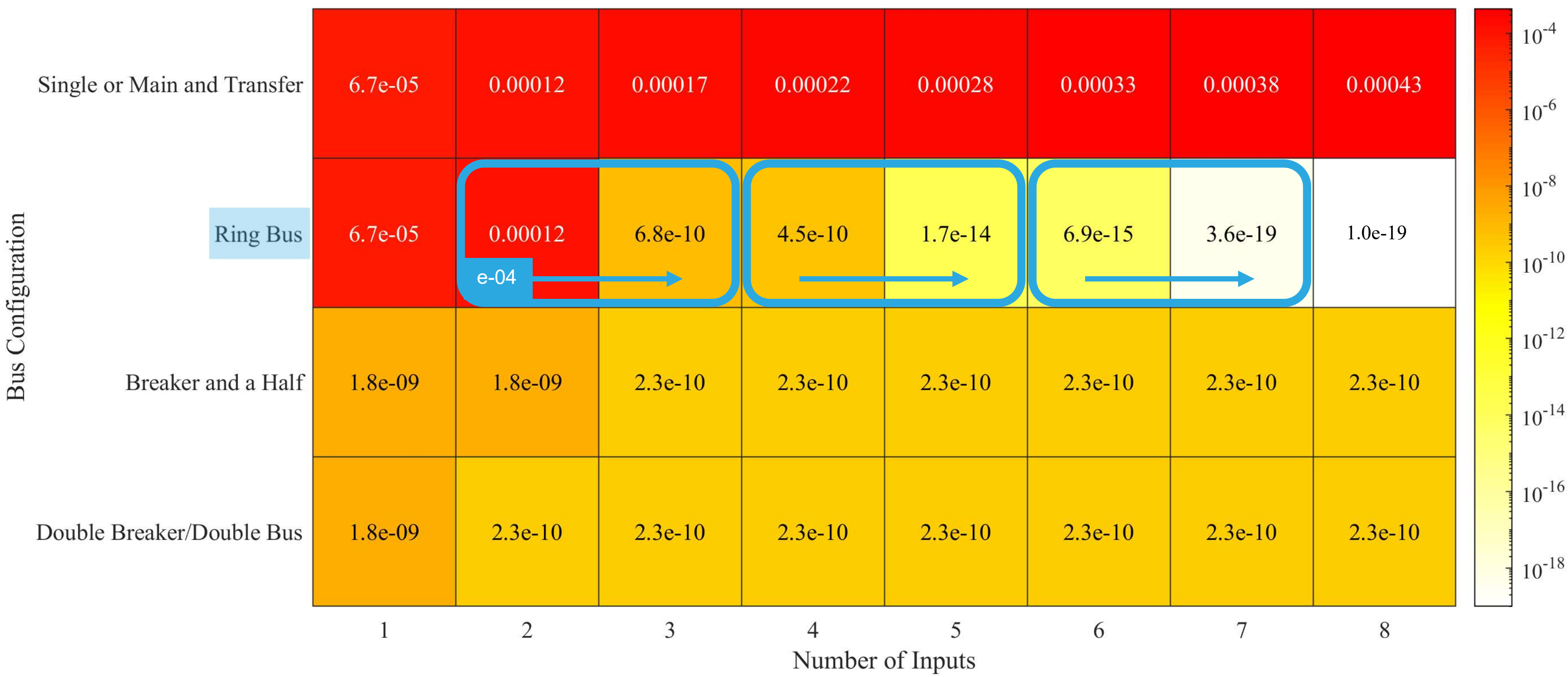
Failure Rate Results

Continual increase in failure rate



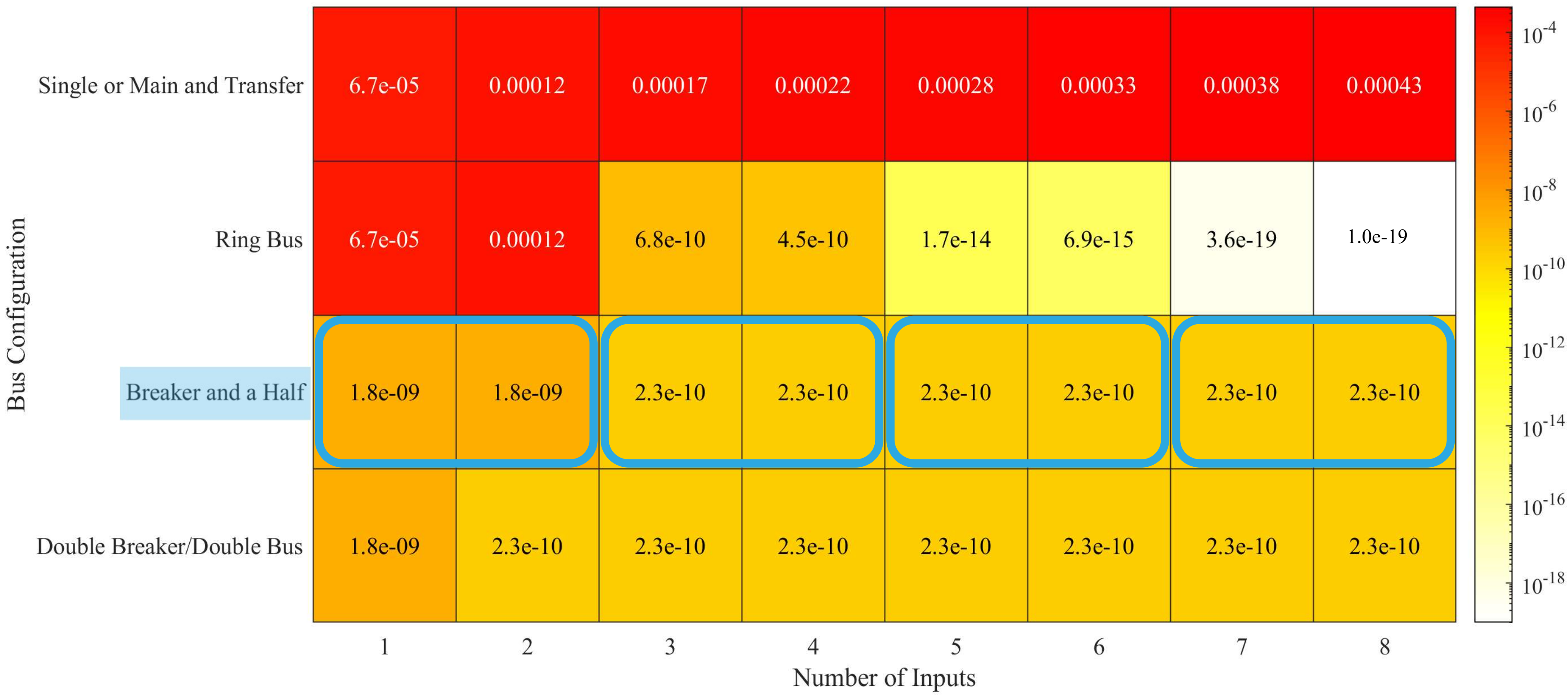
Failure Rate Results

Multiple order of magnitude decreases for the Ring Bus



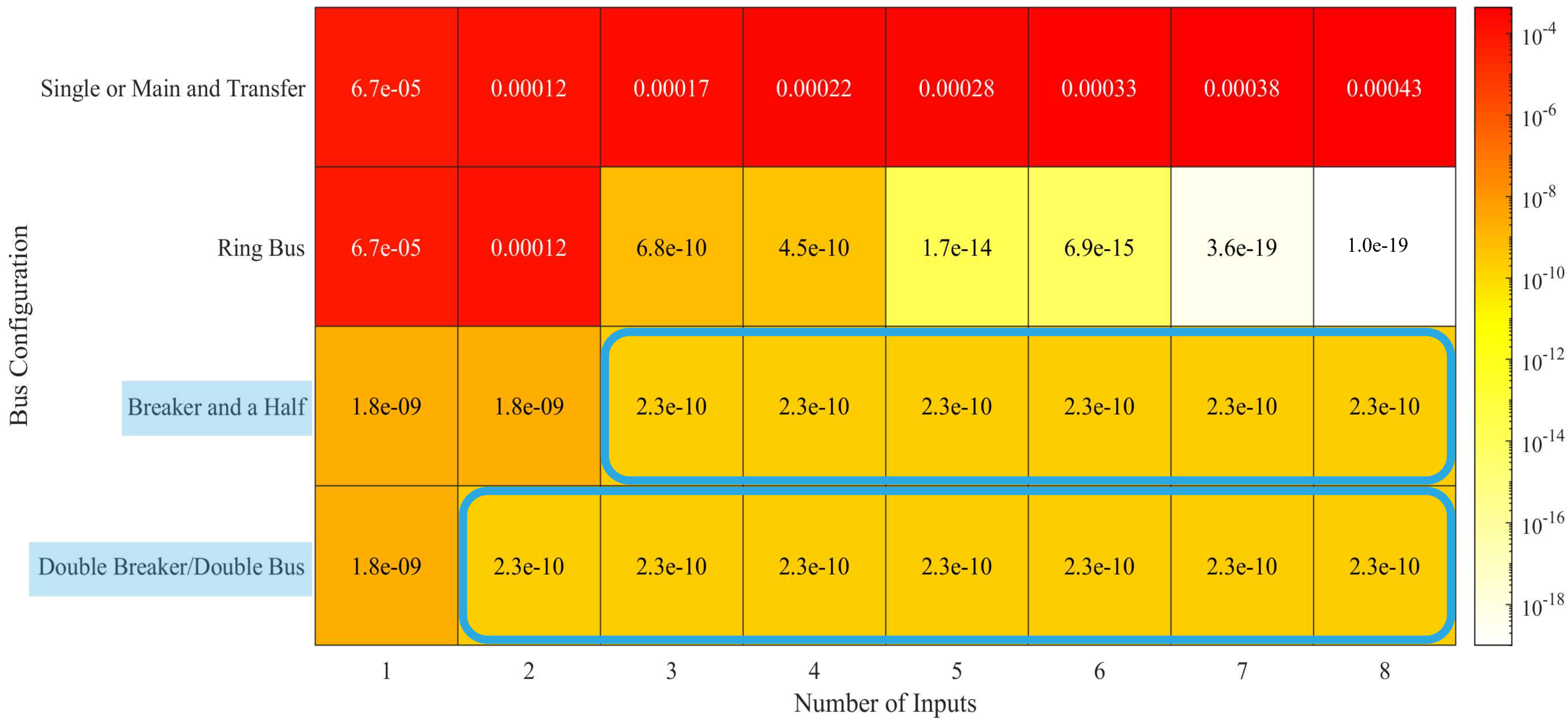
Failure Rate Results

Identical component make up → Identical failure rate pairs



Failure Rate Results

Plateau driven by reliability of busbar pair



Ranking of Reliability based on Number of Inputs

Switch in most reliable from DBB/BAH and RNG when increase from four to five inputs

Number of Inputs

	1	2	3	4	5	6	7	8
High	1. DBB	1. DBB	1. DBB	1. DBB →	1. RNG	1. RNG	1. RNG	1. RNG
	1. BAH	2. BAH	1. BAH	1. BAH	2. DBB	2. DBB	2. DBB	2. DBB
↓	3. RNG	3. RNG	3. RNG	3. RNG	2. BAH	2. BAH	2. BAH	2. BAH
Low	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT

S/MT	Single and Main and Transfer	BAH	Breaker and a Half
RNG	Ring Bus	DBB	Double Breaker/Double Bus

Ranking of Reliability based on Number of Inputs

Single and Main and Transfer configuration are consistently the least reliable

Number of Inputs

	1	2	3	4	5	6	7	8
High	1. DBB	1. DBB	1. DBB	1. DBB	1. RNG	1. RNG	1. RNG	1. RNG
	1. BAH	2. BAH	1. BAH	1. BAH	2. DBB	2. DBB	2. DBB	2. DBB
↓	3. RNG	3. RNG	3. RNG	3. RNG	2. BAH	2. BAH	2. BAH	2. BAH
Low	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT	4. S/MT

S/MT	Single or Main and Transfer	BAH	Breaker and a Half
RNG	Ring Bus	DBB	Double Breaker/Double Bus

Conclusions

- Reliability of the substation generally corresponds to the number of inputs
  - Single and Main and Transfer configurations have a positive correlation
  - All other configurations examined have an inverse correlation
- Double Breaker/Double bus, Breaker and a half, and Ring bus configurations are the most reliable
  - Double Breaker/Double Bus and Breaker and a half for one to four inputs
  - Ring bus for five or greater inputs
- This builds a foundation for quantified understanding of reliability in two parameters, configuration and number of inputs
- Adding cost as a parameter would enhance usefulness of data
  - Cut set numbers are a general indicator
  - Capital costs
  - Operation and maintenance costs

References

[1] 2007. "IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems." IEEE Std 493-2007, Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/IEEESTD.2007.380668.

[2] Tsao, Teng-Fa and Chang, Hong-Chan. 2003. "Composite Reliability Evaluation Model for Different Types of Distribution Systems." IEEE Transactions on Power Systems, 19 (2): 924–930. https://doi.org/10.1109/TPWRS.2003.811174.

Acknowledgements

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4 input Cost Study

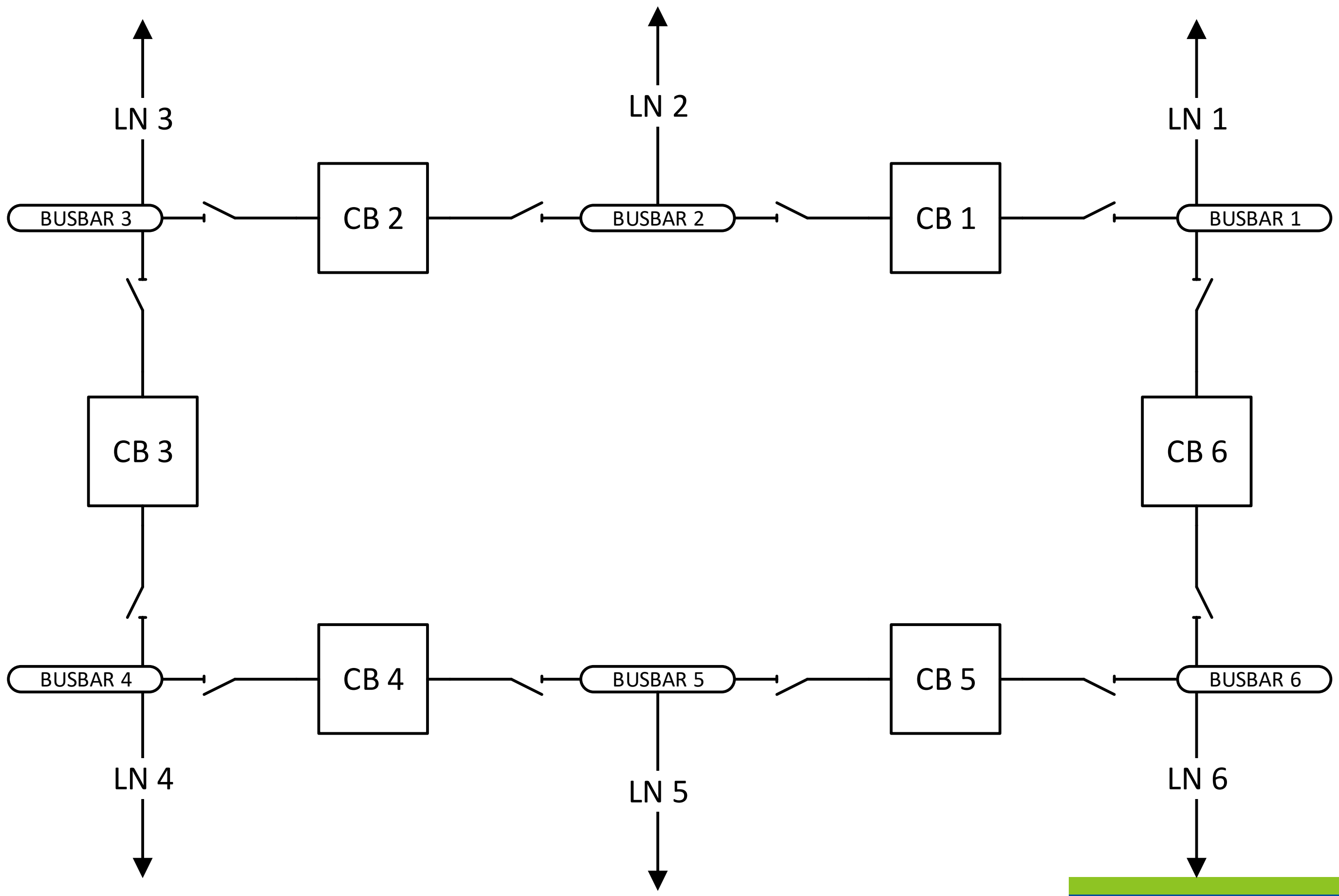
Configuration	Multiplied value	Failure rate [/hr]	Approximate relative cost comparison*
Breaker and a Half	3.59E-10	2.272E-10	1.58
Double Breaker/ Double Bus	4.86E-10	2.271E-10	2.14
Ring Bus	5.18E-10	4.542E-10	1.14
Single	2.24E-04	2.24E-04	1
Main and Transfer	3.20E-04	2.24E-04	1.43

*J. Bardwell et al. "*Design Guide for Rural Substations*," U.S. Department of Agriculture - Rural Utilities Service, USA, RUS Bulletin 1724E-300, 2001. [Online] Available: https://www.rd.usda.gov/sites/default/files/UEP_Bulletin_1724E-300.

Substation Failure States

Substation Configuration	Failure States
Single	1. Any one circuit breaker fails 2. Any one control panel fails 3. The busbar fails
Main and Transfer	1. Any one circuit breaker fails 2. Any one control panel fails 3. The main busbar fails (transfer bus only energized in maintenance)
Ring Bus	1. All breakers or their panels fail 2. Every other busbar fails (non-adjacent) • Odd number of inputs (n): (n+1)/n of n busbars fail, two are adjacent • Even number of inputs (n): n/2 of n busbars fail
Breaker and a Half	1. Both busbars fail (A and B) 2. A busbar and one of the opposite input breakers or control panels fail • Busbar A and all B input circuits (breakers or panels) • Busbar B and all A input circuits (breakers or panels) 3. All middle circuit breakers fail and one A and one B breaker fails
Double Breaker/Double Bus	1. Both busbars fail 2. One of the busbars and all the opposite breakers fail • Busbar A and all B breakers or panels • Busbar B and all A breakers or panels

Ring Bus 6 inputs



Ring Bus 5 inputs