Predicting Distribution System Performance Against Reliability Standards

Nagaraj Ballijepalli
Iowa State University

S.S. (Mani) Venkata
Iowa State University
venkata@iastate.edu

Richard D. Christie
University of Washington
christie@ee.washington.edu

This work supported in part by the Electric Power Research Institute
Vito Longo, Project Manager

Distribution reliability standards

- Regulators are developing reliability standards for distribution systems
- Standards for feeders with SAIDI and SAIFI
  - No feeder more than 2 standard deviations above average (PA)
  - No feeder more than 400% above average (TX)
  - No feeder in worst 2% for two consecutive years (MD)

Distribution reliability standards

- Standards for system on SAIDI and SAIFI
  - System annual reliability not over 105% of average (TX)

- Reliability is a random process - these standards **will** be violated
- How often will a utility violate them?

Reliability distributions

- Average values are not enough to predict rate of violation of these standards
- Need to know the probability distribution
- Standards appear to assume a Gaussian distribution, e.g.
  - 2 standard deviations = 2.3% probability of violation

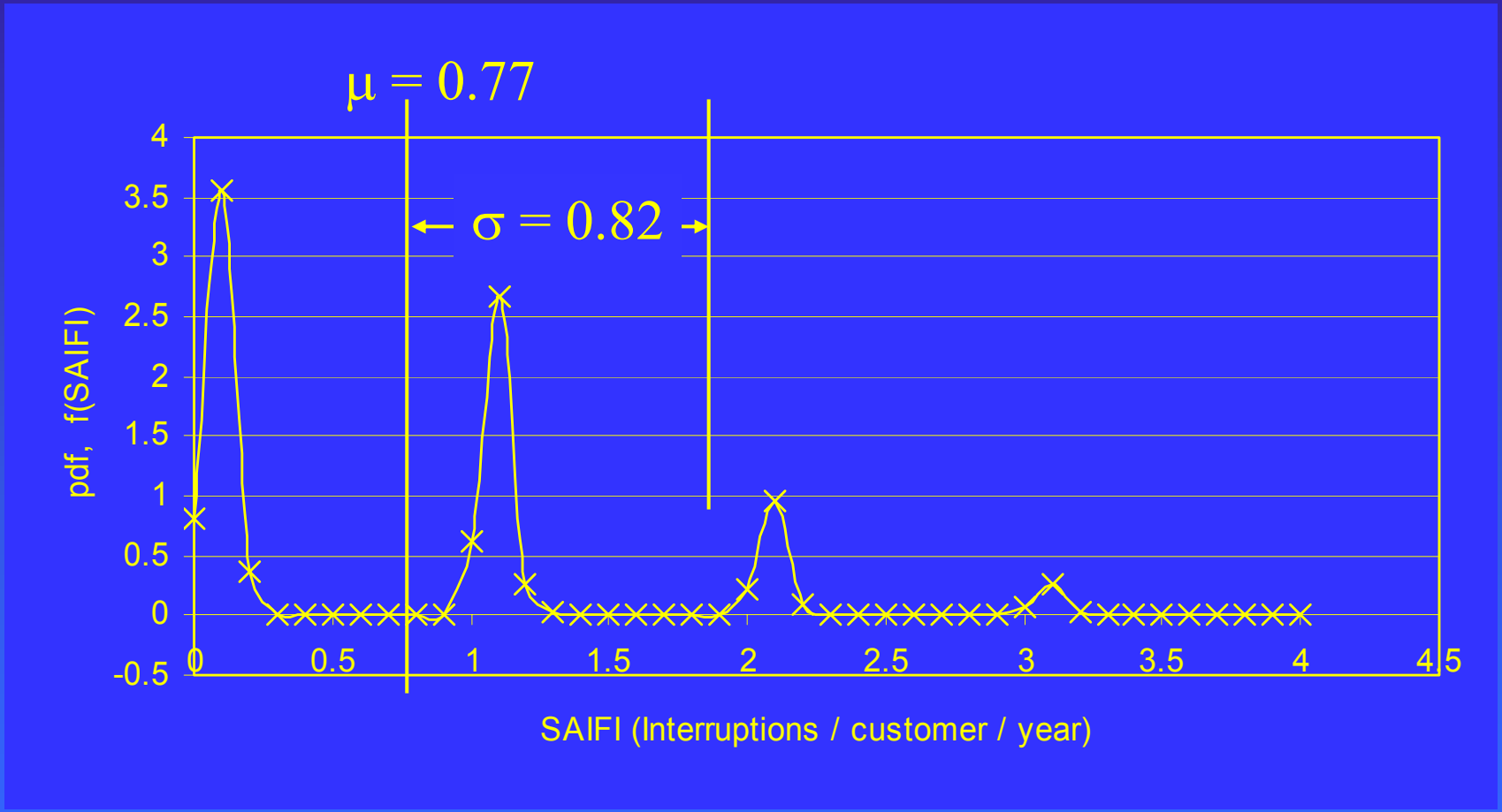
Reliability distributions

- Are feeder SAIDI and SAIFI distributions Gaussian?
- Use Monte Carlo analysis to check
  - 100 feeder system
  - detailed protection and repair models
  - segment fault rates and mean time to repair
  - 10,000 years of simulation

Feeder SAIDI

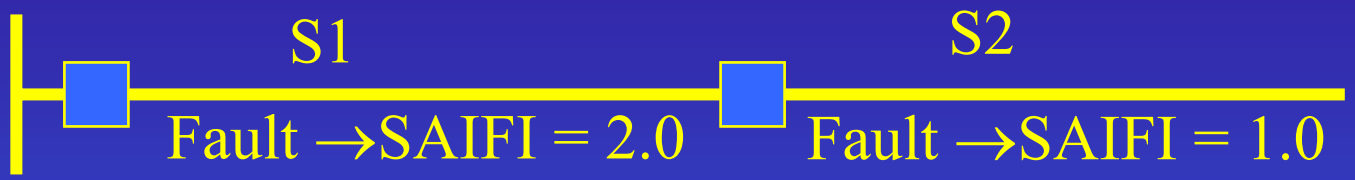
- Not Gaussian! (Other feeders similar)

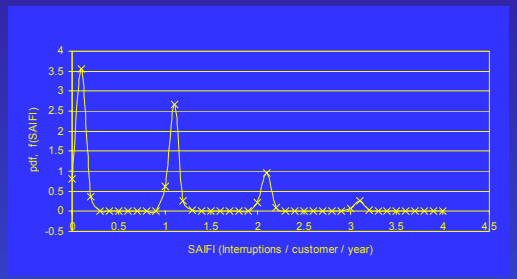
Feeder SAIFI



- Not Gaussian either

Why the SAIFI distribution?





- In any given simulated year, there could be
  - No fault - SAIFI for that year is zero
  - Fault on S1 - SAIFI for that year is 2.0
  - Fault on S2 - SAIFI for that year is 1.0
  - Odds of faults on S1 and S2 in same year very low
  - So most years SAIFI is 0, 1.0 or 2.0
  - Small variations may be laterals

Feeder SAIFI distribution

- Multimodal distribution due to segmentation from protection and switching
- Faults are discrete random events
- Seen in most feeders in example, and by other researchers
- Not seen in SAIDI because repair time is a continuous random variable that spreads out effect of a fault

How can probability of violation be predicted?

- Run Monte Carlo simulation
- Get 10,000 annual SAIDI or SAIFI values for each feeder
- Apply reliability criteria to this data

Feeder criterion F0

- F0 criterion: “no feeder shall exceed $\mu+x\sigma$” where x is set by the regulators
- PA criterion is F0 with $x = 2$
- Objective is to identify poorly performing feeders, i.e. separate good reliability from bad reliability
- Expect highs and lows (differentiation)
- Expect correlation with high SAIDI or SAIFI

Results: F0 criterion

Feeder	SAIDI	F0 Measure (%)	SAIFI	F0 Measure (%)
F78C	6.21	4.81	0.906	5.76
F57C	5.33	4.54	0.825	4.42
F84A	3.95	3.20	1.463	4.31
F78B	3.78	3.72	0.768	3.87
F77D	3.16	3.30	0.701	2.84
F84B	2.53	2.15	0.915	5.10
F57B	2.40	2.81	0.712	3.43
F57A	2.32	3.08	0.416	6.90
F57D	1.18	1.71	0.393	5.34
F78A	0.61	4.06	0.240	5.79

- Randomly selected feeders
- Most F0's about 5% - little differentiation
- Poor correlation with SAIDI, SAIFI

Results: F0 criterion

- F0 Criterion ineffective at identifying poorly performing feeders

Feeder criteria F1 and F2

- F1 criterion: No feeder more than y% over system average for two consecutive years
  - Texas: y = 400%
- F2 criterion: No feeder in the worst z% of feeders for two consecutive years
  - Texas: z = 10%
  - Maryland: z = 2%

Results: F1 and F2 criteria for SAIDI

Feeder	SAIDI	F1Measure (%)	F1 Rank	F2 Measure (%)	F2 Rank
F71B	13.38	11.89	1	17.22	1
F72A	8.95	5.75	2	10.95	3
F28B	7.22	4.91	3	13.19	2
F43A	6.78	3.60	4	8.51	4
F78C	6.22	2.78	5	5.24	9
F57C	5.33	2.04	7	3.75	14
F14A	5.32	1.98	8	3.71	15
F43B	5.17	2.29	6	8.31	5
F47B	5.11	1.62	12	4.35	12
F47D	4.92	1.83	9	6.00	8

- 10 worst SAIDIs
- Good differentiation
- Good correlation with SAIDI

Results: F1 and F2 Criteria for SAIFI

Feeder	SAIFI	F1 Measure (%)	F1 Rank	F2 Measure (%)	F2 Rank
F28B	2.10	9.91	1	32.26	1
F43B	1.87	7.73	2	24.26	2
F17A	1.70	4.32	4	20.17	3
F77B	1.69	4.39	3	18.75	4
F17B	1.59	2.40	6	15.50	5
F43A	1.54	3.25	5	13.98	6
F47D	1.47	1.98	7	12.69	7
F84A	1.46	1.06	10	10.06	8
F27A	1.41	0.67	15	8.50	9
F47A	1.33	0.49	18	7.39	12

- 10 worst SAIFIs
- Good differentiation
- Good correlation with SAIFI

Results: F1 and F2 criteria

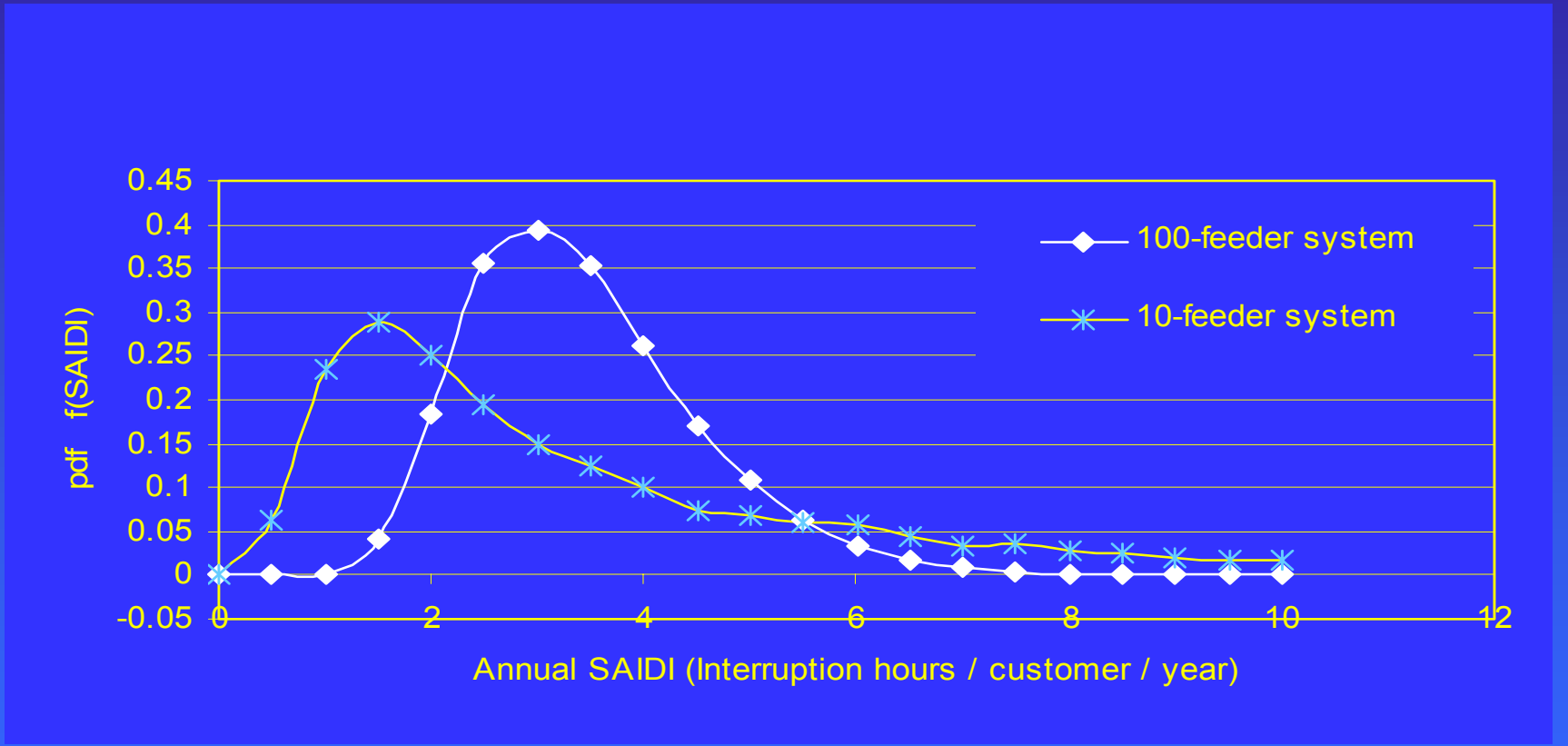
- These criteria are more effective at identifying poor feeder performance

- Which is worst, SAIDI or SAIFI?
  - F1 and F2 convert SAIDI and SAIFI into criteria violations
  - Could just order by probability of violation

System Criterion S0

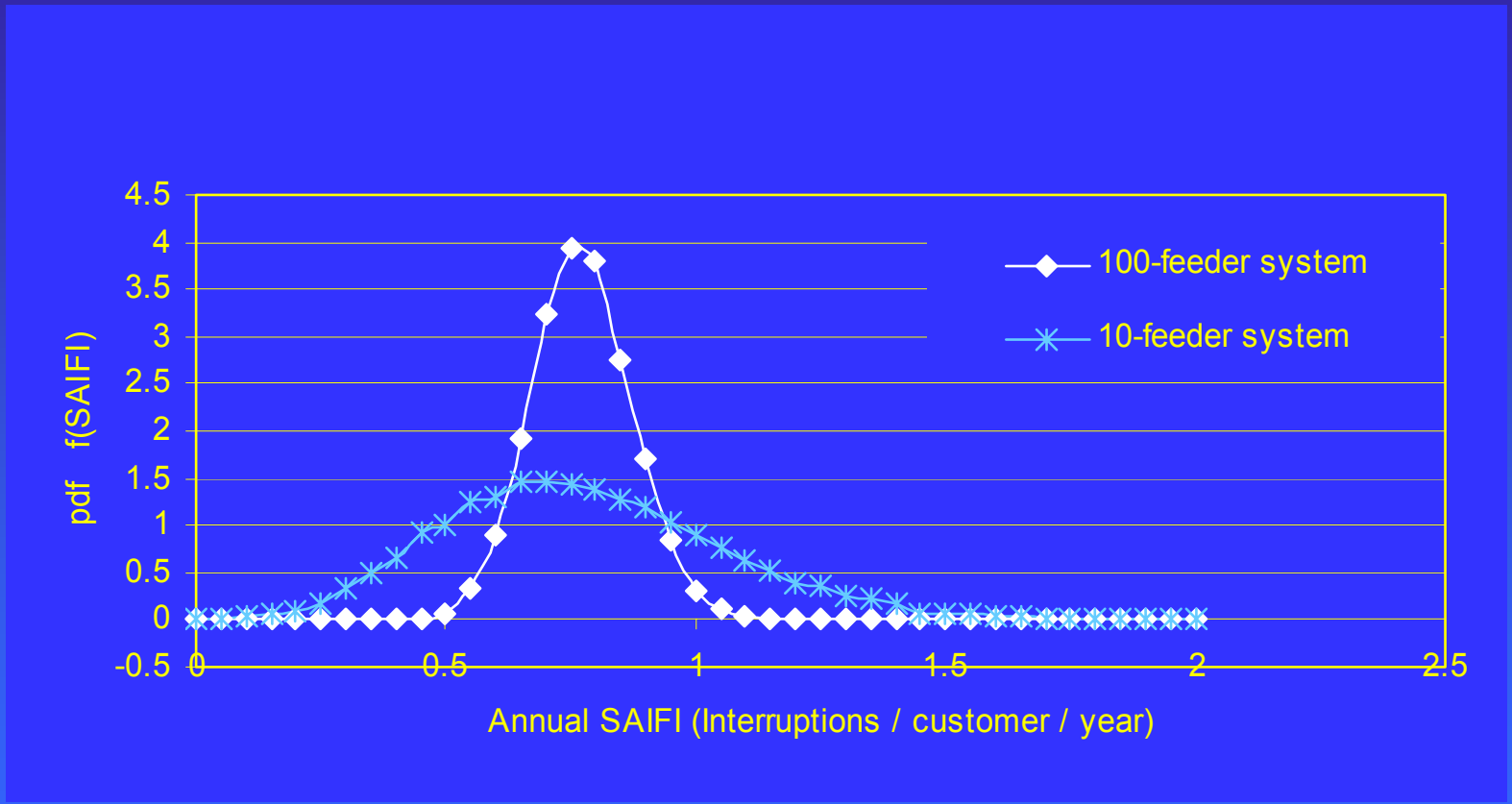
- S0 Criterion: Annual system reliability shall be less than y% of a benchmark value (long term average)
- Texas: y = 105%
- Expect same violation rate for systems of different size
- Expect more violations for higher per-mile fault rates

Results: SAIDI distribution



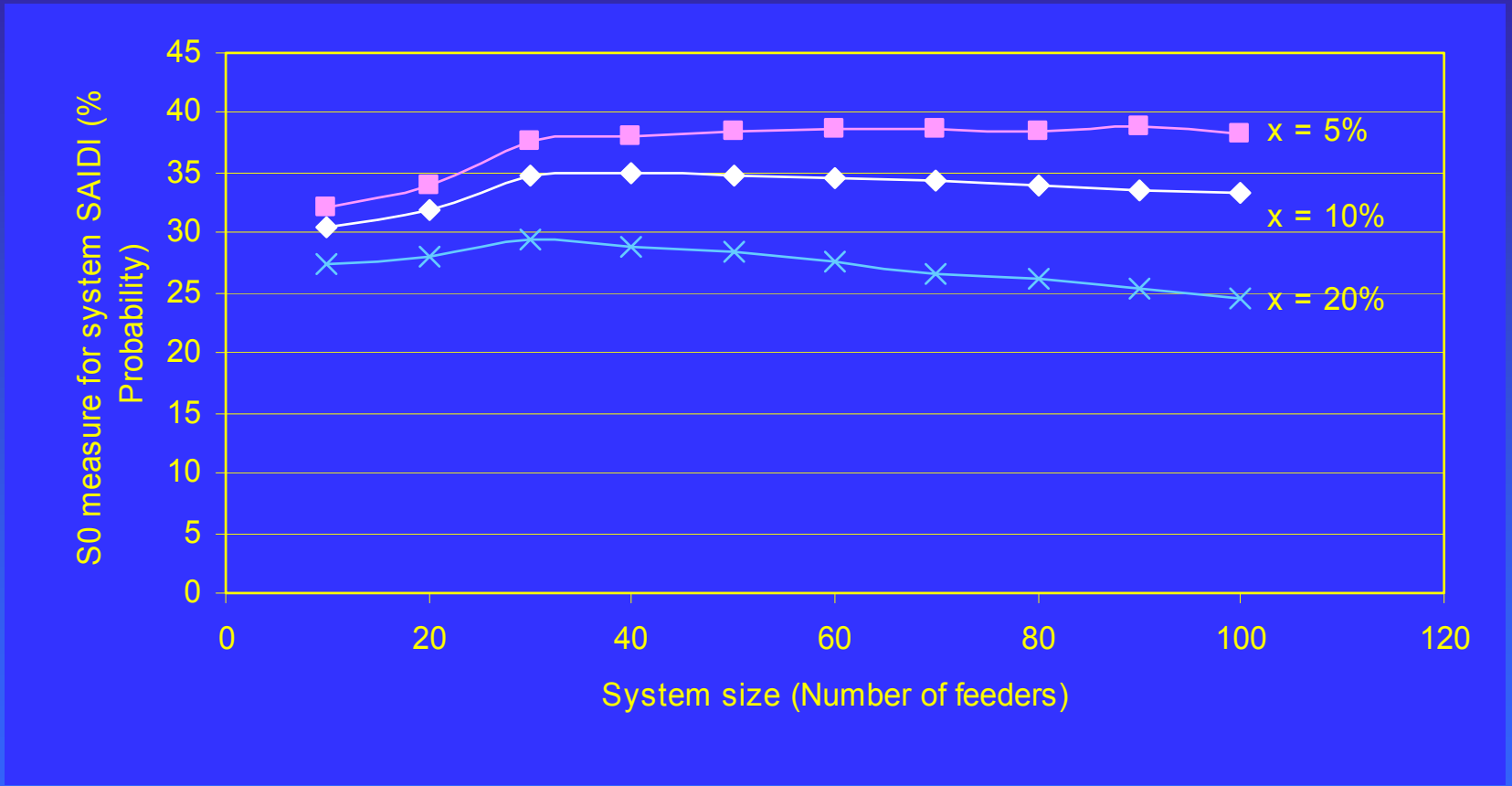
Smaller system has larger standard deviation

Results: SAIFI distribution



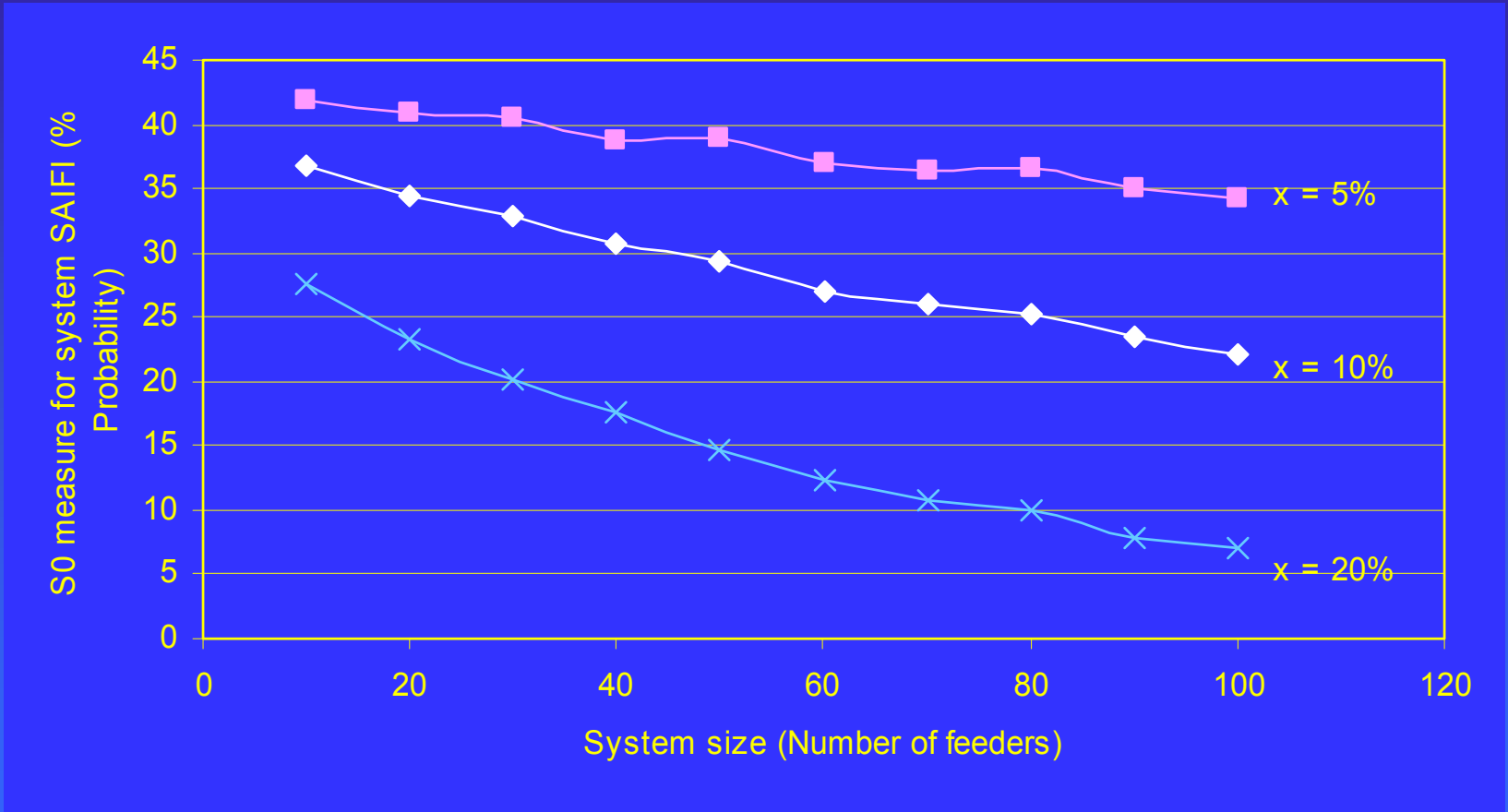
Smaller system has larger standard deviation

Results: S0 criterion for SAIDI



High probability of violation - about 1 year in 3

Results: S0 criterion for SAIFI



Strong dependence on system size

Results: S0 criterion for SAIDI: effect of fault rate

Systems with higher component failure rates have fewer S0 violations

Results: S0 criterion for SAIFI: effect of failure rate

Systems with higher component failure rates have fewer S0 violations

System criterion S1

- S1 Criterion (proposed): System reliability shall not exceed y% of benchmark for two consecutive years
- Graphs about the same as S0, except probability of violation reduced to about 10%
- S1 for SAIFI still has strong size dependency

Conclusions

- Power system reliability is not Gaussian
- Monte Carlo analysis is an effective tool for analyzing the effects of reliability criteria
- Multi-year feeder reliability criteria are more effective at identifying poorly performing feeders
- System reliability criteria on SAIFI shows dependency on system size - smaller systems will have more violations

Conclusions

- Systems with poorer system reliability will have fewer system criteria violations
- Perhaps system reliability criteria should take the log-normal nature of reliability probability distributions into account