Basic Models and Methodologies for Common Mode and Dependent Transmission Outage Events

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INTRODUCTION

The primary assumption in most reliability studies is that component failures are independent events and that system state probabilities can be determined by simple multiplication of the relevant probabilities [1].

This assumption simplifies the calculation process but is inherently optimistic and can in certain cases be quite misleading.

INTRODUCTION

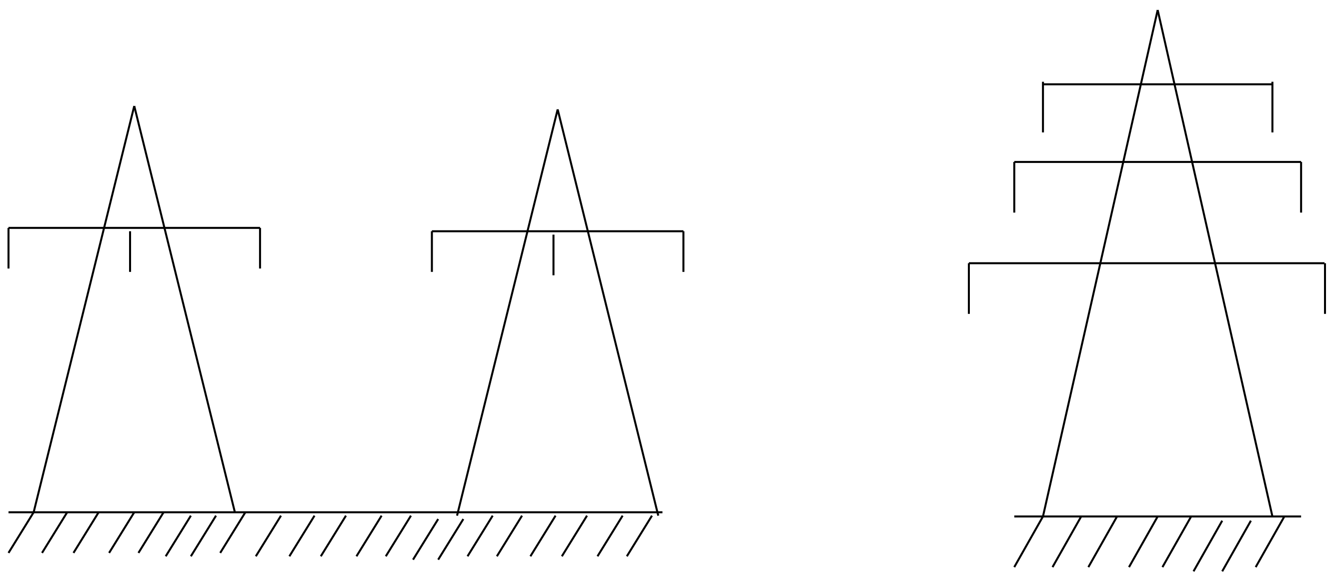
The IEEE Subcommittee on the Application of Probability Methods initiated an investigation of this problem through a Task Force on Common Mode Outages of Bulk Power Supply Facilities and published a paper in 1976 [4]. This paper emphasized the importance of recognizing the existence of common mode outages and recommended a format for reporting the data.

The APM Subcommittee defined a common mode failure:

"as an event having a single external cause with multiple failure effects where the effects are not consequences of each other" [4].

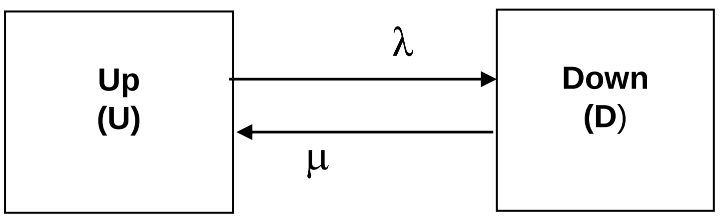
INTRODUCTION

Fig. 1. Two different arrangements for two transmission circuits



BASIC MODELS

The basic component model [1] in power system reliability/availability analysis is the two state representation in which a component is either in an operable or inoperable condition. In this model, λ is the failure rate in failures per year and μ is the repair rate in repairs per year. The average repair time r is the reciprocal of the repair rate.



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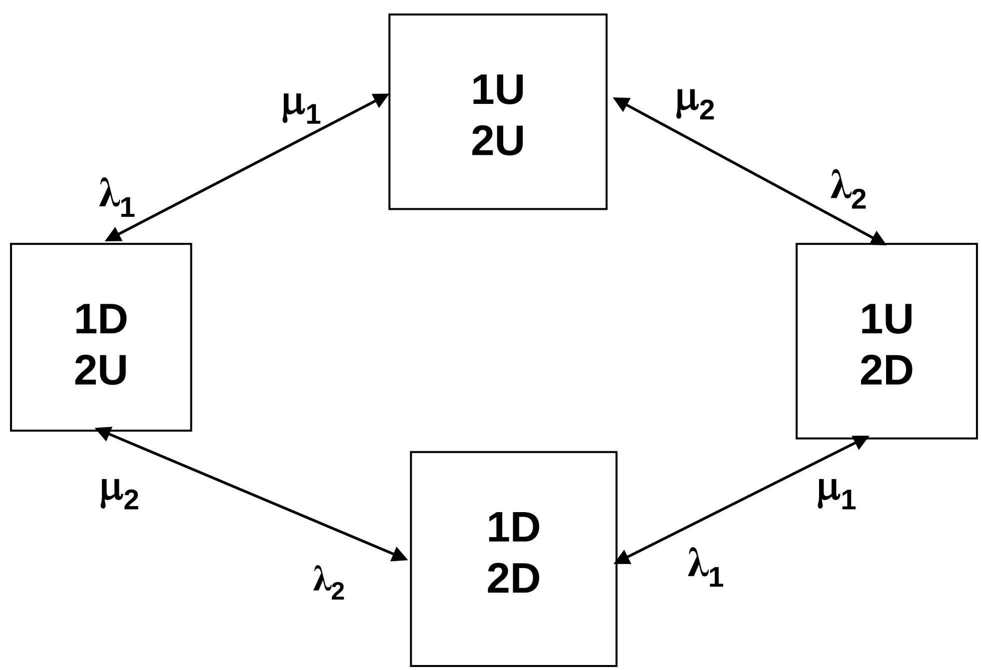
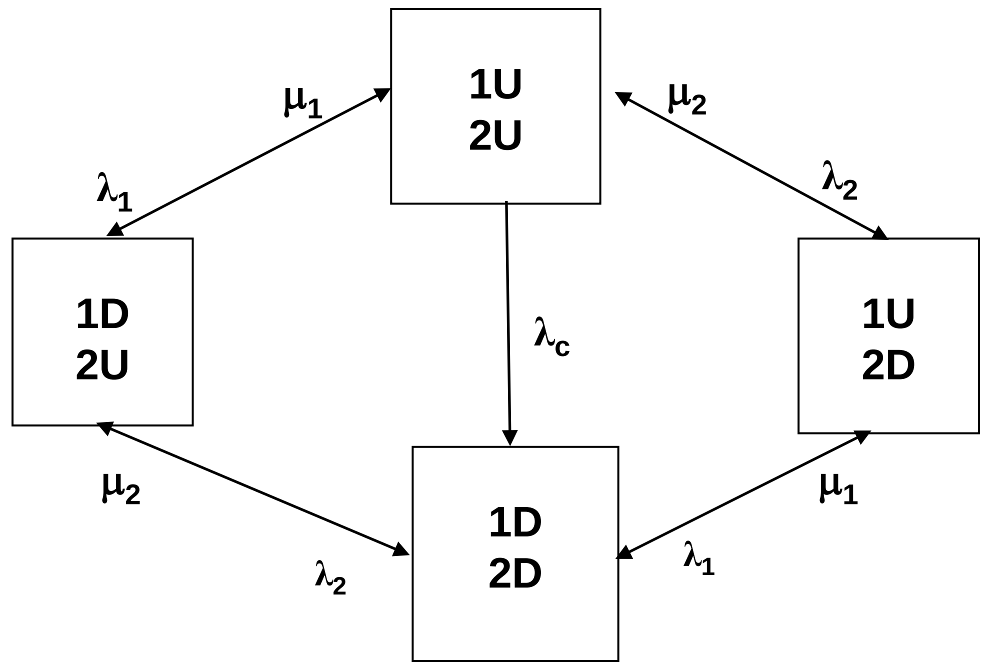
Two non-identical independent component model



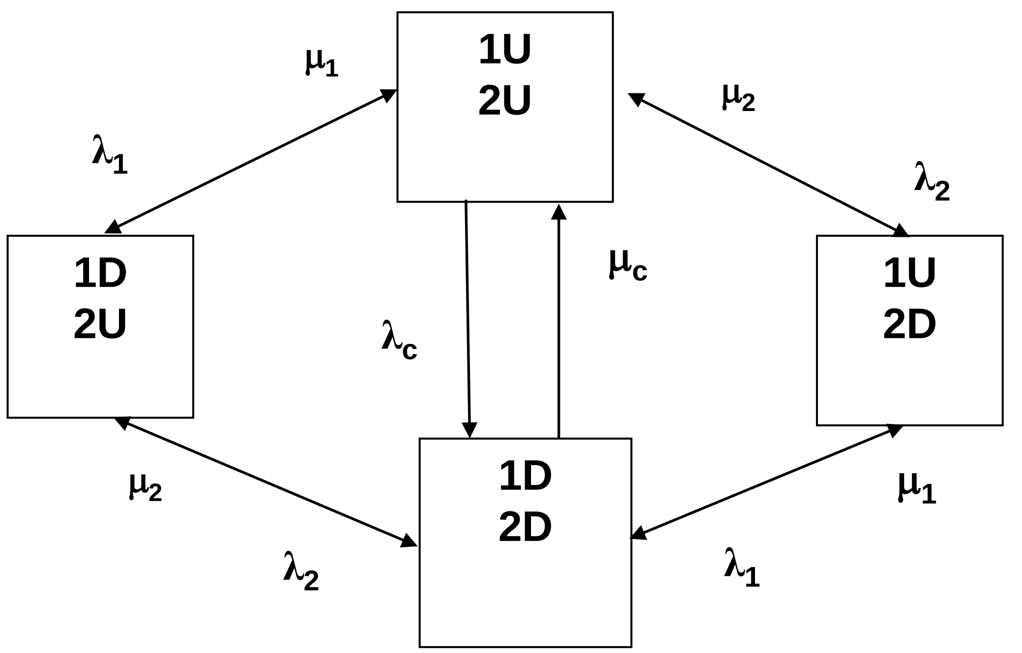
The APM Subcommittee proposed a two component system model incorporating common mode failure.

Model 1.



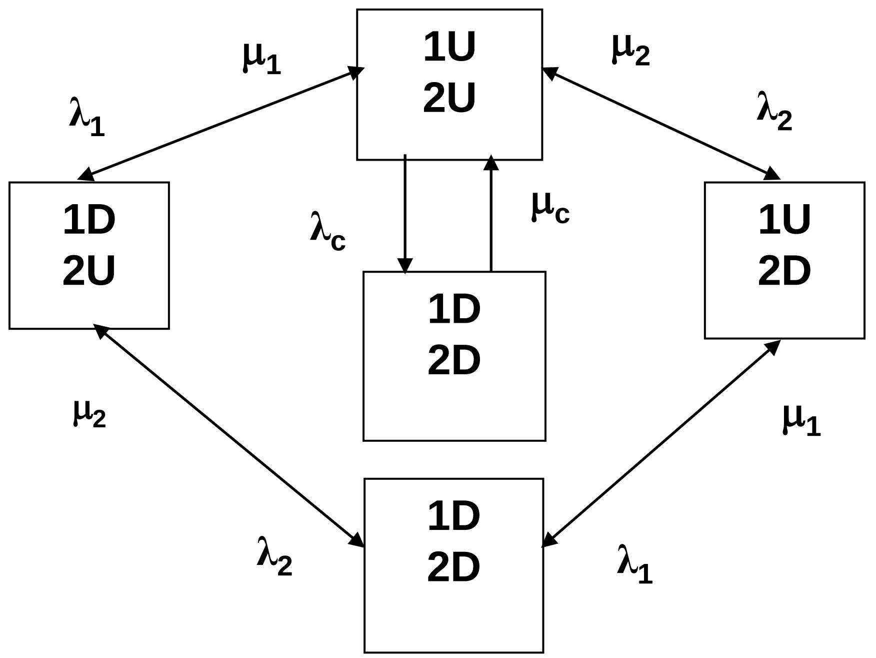
Modified common mode model for two non-identical components

Model 2.



Separate repair process common mode model for two non-identical components.

Model 3.



Markov analysis of Model 1

$$P_4 = \lambda_1 \lambda_2 (\lambda_1 + \lambda_2 + \mu_1 + \mu_2) + \lambda_c (\lambda_1 + \mu_2)(\lambda_2 + \mu_1) / D$$

$$D = (\lambda_1 + \mu_1)(\lambda_2 + \mu_2)(\lambda_1 + \lambda_2 + \mu_1 + \mu_2)$$
$$+ \lambda_c[(\lambda_1 + \mu_1)(\lambda_2 + \mu_1 + \mu_2) + \mu_2 (\lambda_2 + \mu_2)]$$

If the two components are identical

$$P_4 = 2\lambda^2 + \lambda_c (\lambda + \mu) / 2(\lambda + \mu)^2 + \lambda_c (\lambda + 3\mu)$$

Consider a transmission line with λ = 1.00 f/yr

and r = 7.5 hours (μ = 1168 r/yr).

The line unavailability (U) is $\frac{\lambda}{\lambda+\mu}$ = 0.000855

If λ_c = 0 in Model 1, the probability of both lines out of service (U_s) is 0.00000073.

If λ_c = 0.01 (l% of λ), U_s = 0.000005

= 0.043800 hrs/yr

If λ_c = 0.10 (10% of λ), U_s = 0.00004350

= 0.38106 hrs/yr

The basic reliability indices for Model 1 (Fig. 3) can be estimated using an approximate method [1].

System failure rate = $\lambda_s = \lambda_1 \lambda_2 (r_1 + r_2) + \lambda_c$

Average system outage time = $r_s = (r_1 r_2)/(r_1 + r_2)$

System unavailability = $U_s = \lambda_s r_s$

Reliability indices for a range of λ_c values

λ_c/λ %	λ_s f/yr	r_s hrs	U_s	U_s hrs/yr
0	0.001712	3.75	0.00000073	0.006
1.0	0.011712	3.75	0.00000501	0.044
2.5	0.026712	3.75	0.00001144	0.100
5.0	0.051712	3.75	0.00002214	0.194
7.5	0.076712	3.75	0.00003284	0.288
10.0	0.101712	3.75	0.00004354	0.381
15.0	0.151712	3.75	0.00006495	0.569

The approximate method approach can also be applied to Model 2

In this case:

$$\lambda_s = \lambda_1 \lambda_2 (r_1 + r_2) + \lambda_c$$

$$r_s = (r_1 r_2 r_c) / (r_1 r_2 + r_2 r_c + r_c r_1)$$

$$U_s = \lambda_s r_s$$

If $\lambda_c = 0.1$(10% of λ) and $r_c = 15$ hrs

$\lambda_s = 0.101712$ f/yr

$U_s = 0.00003483 = 0.305$ hrs/yr

Approximate method applied to Model 3

In this case:

$$\lambda_s = \lambda_1 \lambda_2 (r_1 + r_2) + \lambda_c$$

$$U_s = \lambda_1 \lambda_2 r_1 r_2 + \lambda_c r_c$$

$$r_s = U_s / \lambda_s$$

If $\lambda_c = 0.1$ f/yr and $r_c = 15$ hrs

$\lambda_s = 0.101712$ f/yr

$U_s = 0.00017197 = 1.506$ hrs/yr

$r_s = 14.81$ hrs

Reliability index comparison for the three models

Reliability Index	Model 1 Figure 3	Model 2 Figure 5	Model 3 Figure 6
λ_s f/yr	0.101712	0.101712	0.101712
r_s hrs	3.75	3.00	14.81
U_s hrs/yr	0.381	0.305	1.506

Dependent Outage Events

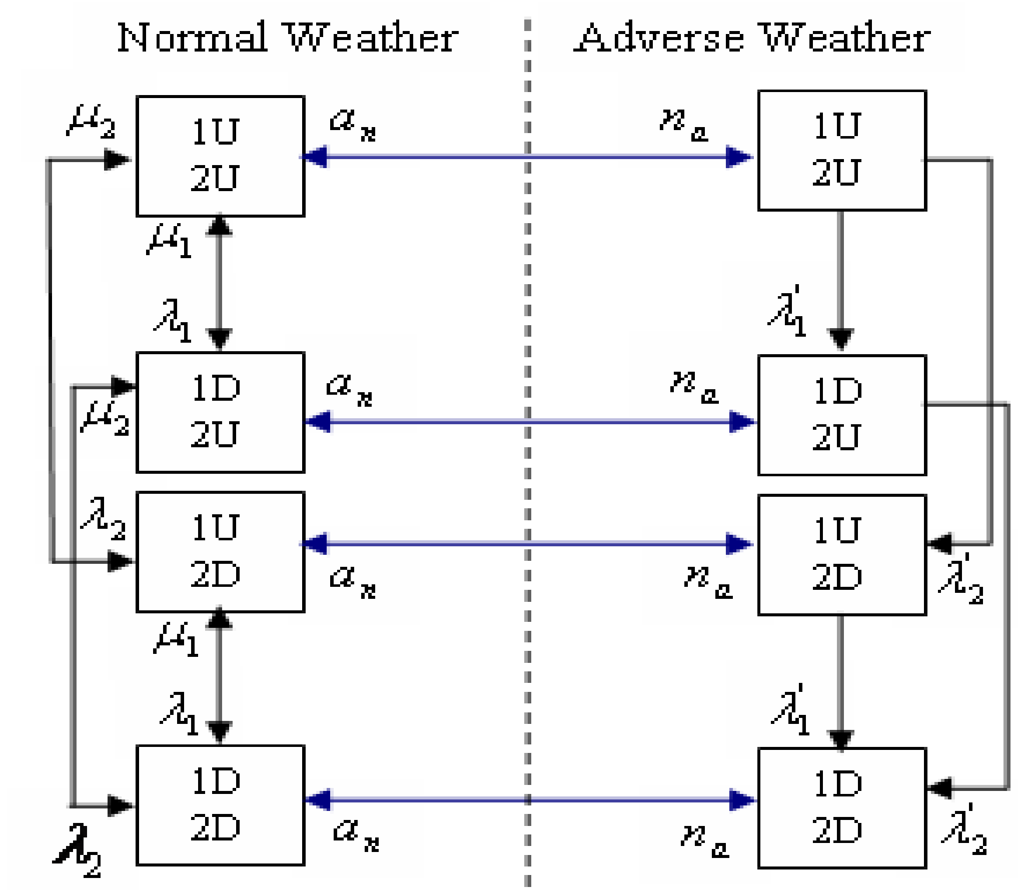
A dependent outage is an event which is dependent on the occurrence of one or more other outages or events.

Extreme weather conditions can create significant increases in transmission element stress levels leading to sharp increases in component failure rates. The probability of a transmission line failure is therefore dependent on the intensity of the adverse weather stress to which the line is subjected. The phenomenon of increased transmission line failures during bad weather is generally referred to as "failure bunching".

Dependent Outage Events

This condition is not a common mode failure event and should be recognized as overlapping independent failure events due to enhanced transmission element failure rates in a common adverse environment.

Independent failure events with a two state weather model



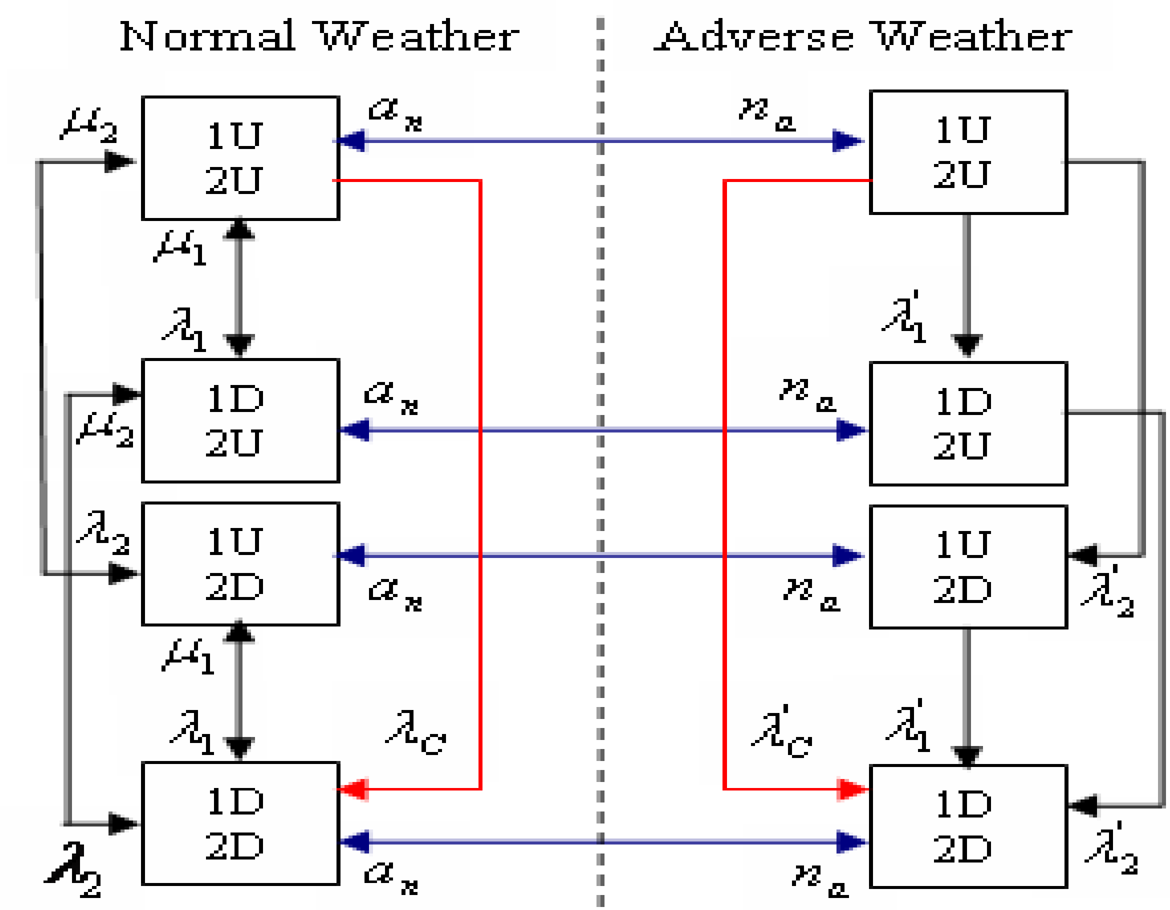
Basic data

Average failure rate of each component, λ = 1.0 f/yr
Average repair rate for each component, μ = 1168 rep/yr
Average duration of normal weather, N = 200 hrs
Average duration of adverse weather, A = 2 hrs

Average duration of major adverse weather,
MA = 1 hr

% of line failures occurring in adverse weather (F)	System failure rate (f/yr)	System unavailability (hrs/yr)
0	0.0017	0.01
10	0.0022	0.01
20	0.0035	0.02
30	0.0058	0.03
40	0.0089	0.05
50	0.0128	0.07
60	0.0176	0.10
70	0.0232	0.13
80	0.0295	0.17
90	0.0367	0.21
100	0.0446	0.26

State space model for independent and common mode failure events with a two state weather model



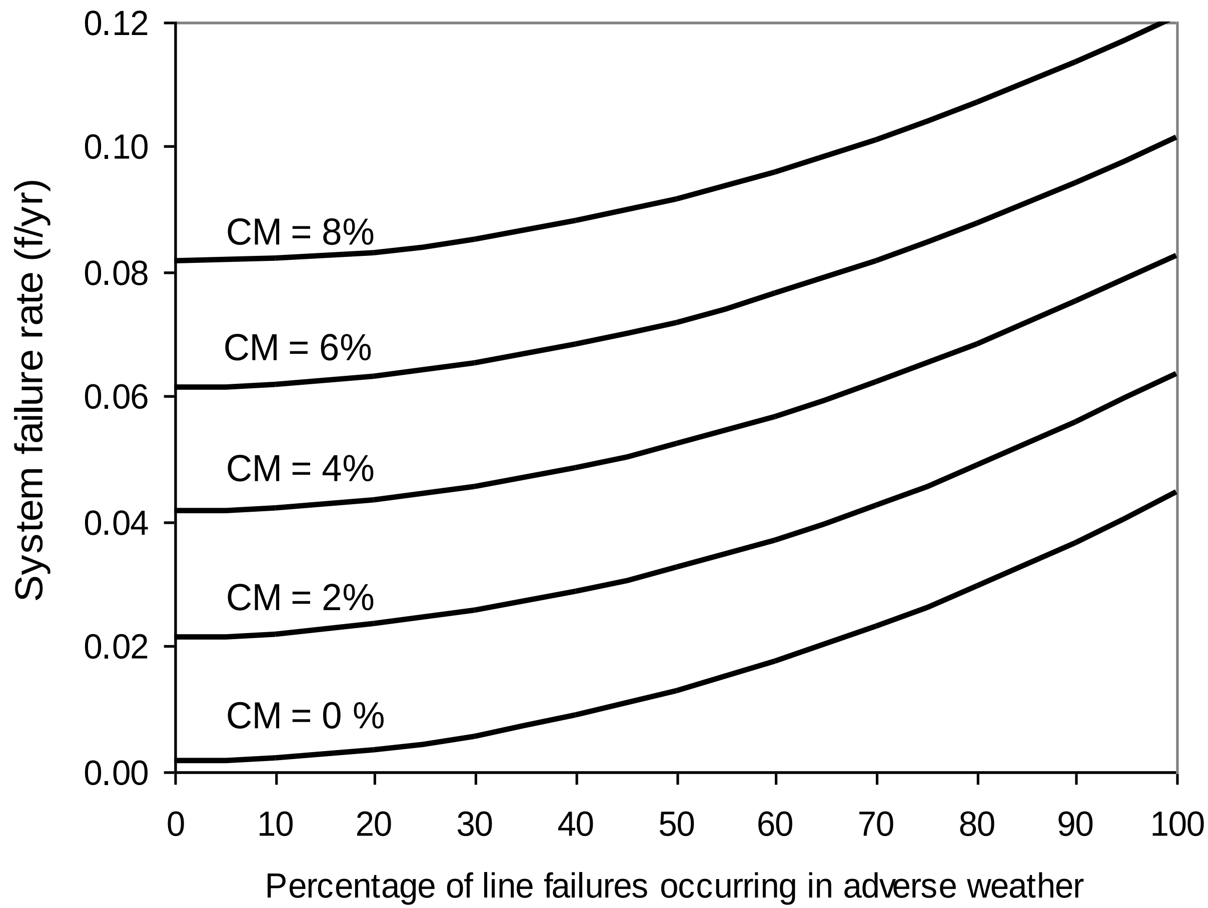
Independent and common mode failure events with a two state weather model. CM=1%

% of line failures occurring in adverse weather	System failure rate (failures/year)	System unavailability (hours/year)
0	0.0117	0.04
10	0.0122	0.05
20	0.0135	0.06
30	0.0157	0.07
40	0.0188	0.09
50	0.0227	0.12
60	0.0274	0.15
70	0.0329	0.18
80	0.0392	0.22
90	0.0463	0.27
100	0.0541	0.31

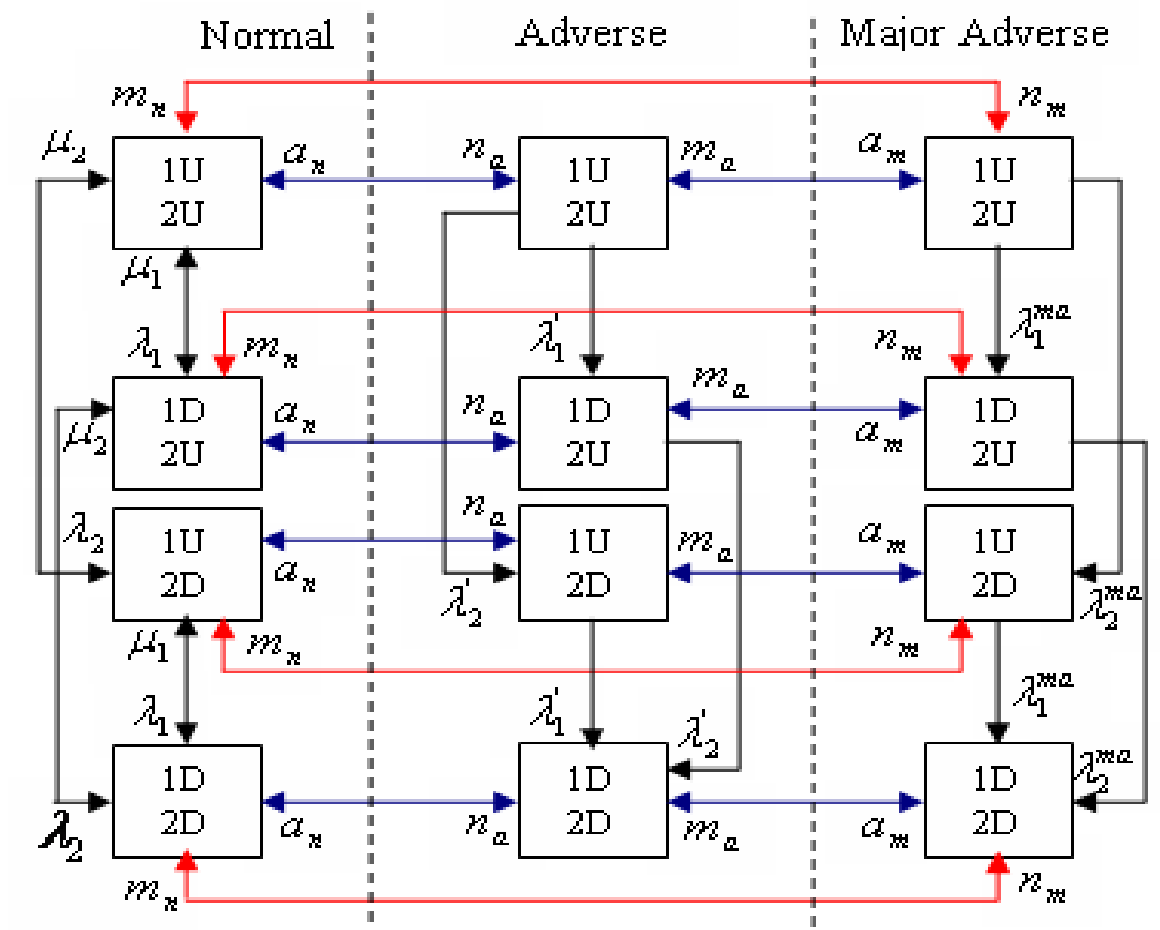
Independent and common mode failure events with a two state weather model. CM=10%

% of line failures occurring in adverse weather (F)	System failure rate (failure/year)	System unavailability (hours/year)
0	0.1016	0.38
10	0.1020	0.41
20	0.1032	0.43
30	0.1052	0.47
40	0.1079	0.50
50	0.1114	0.54
60	0.1157	0.59
70	0.1207	0.64
80	0.1263	0.69
90	0.1327	0.75
100	0.1397	0.81

Effect of independent failure, common mode failure and adverse weather on the system failure rate with a two-state weather model



State space model for independent failures with a three-state weather model



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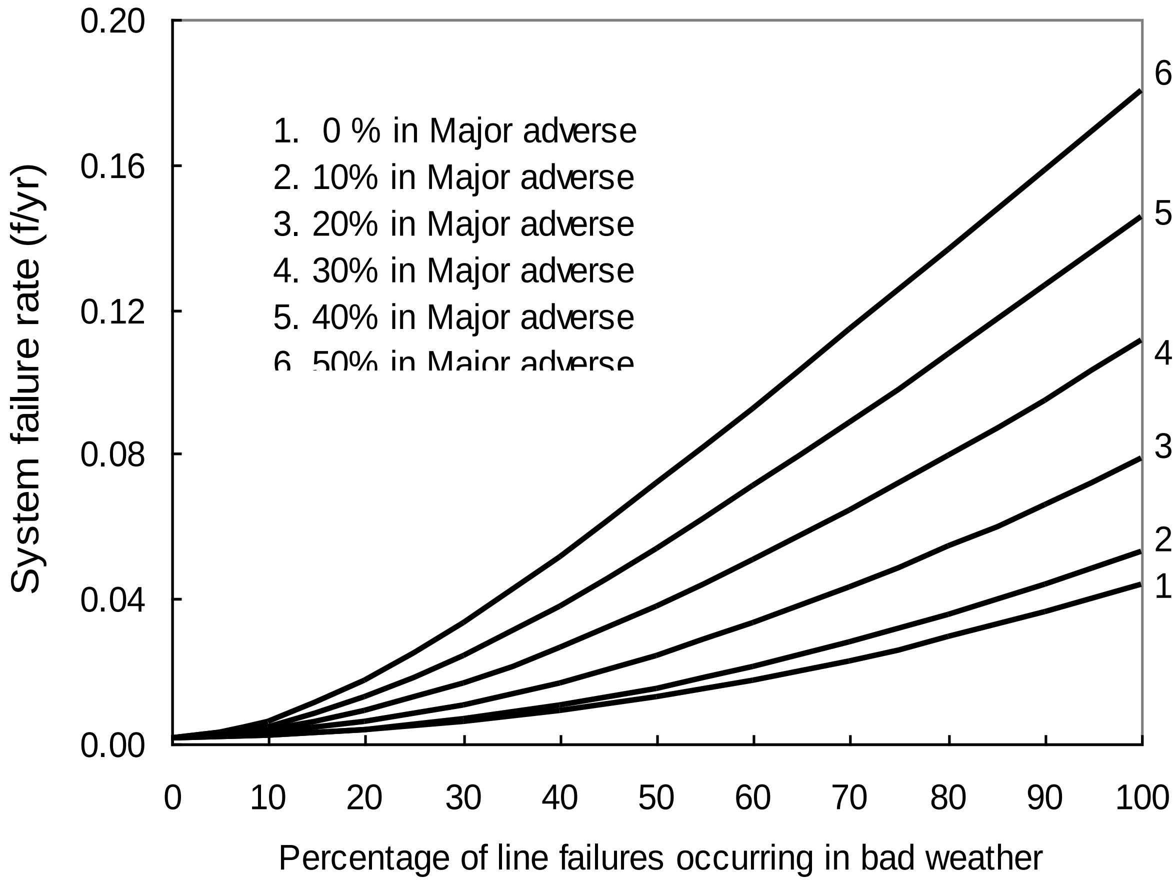
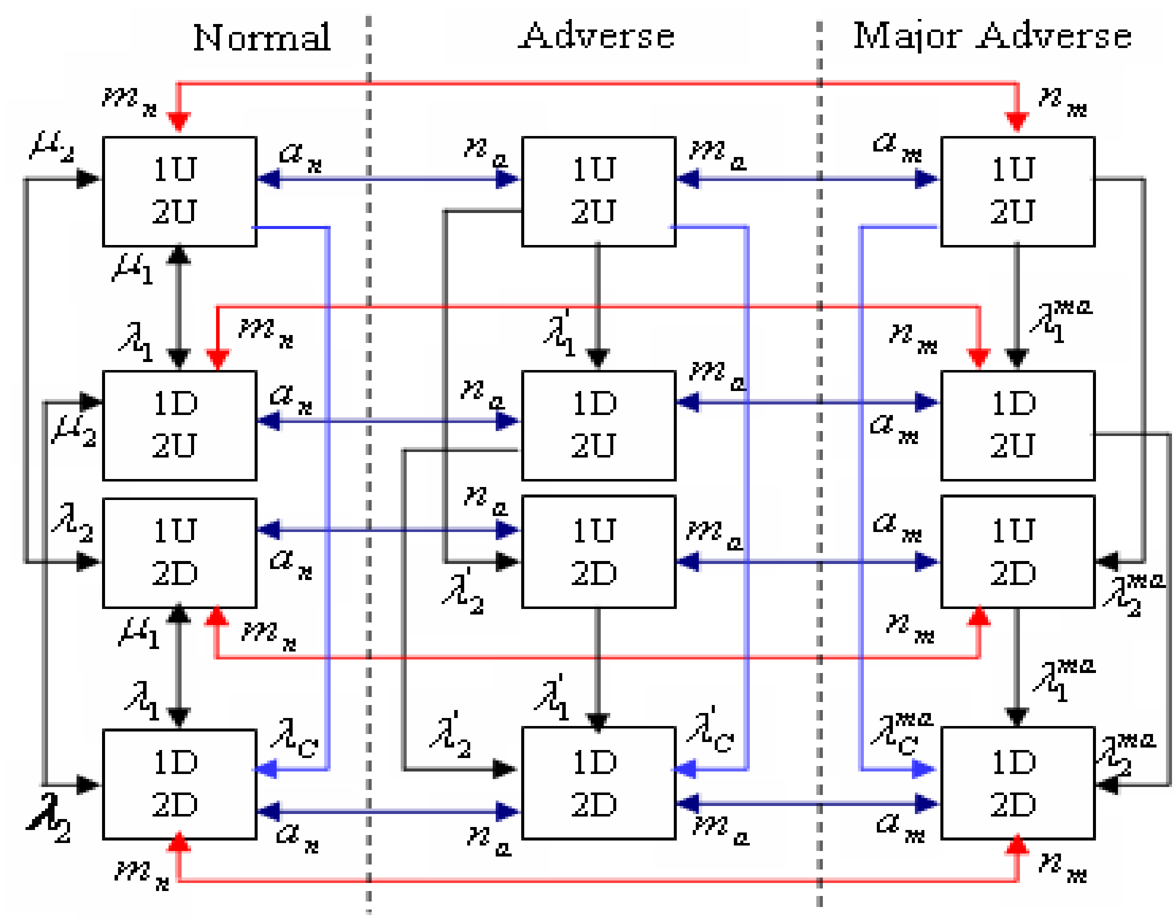
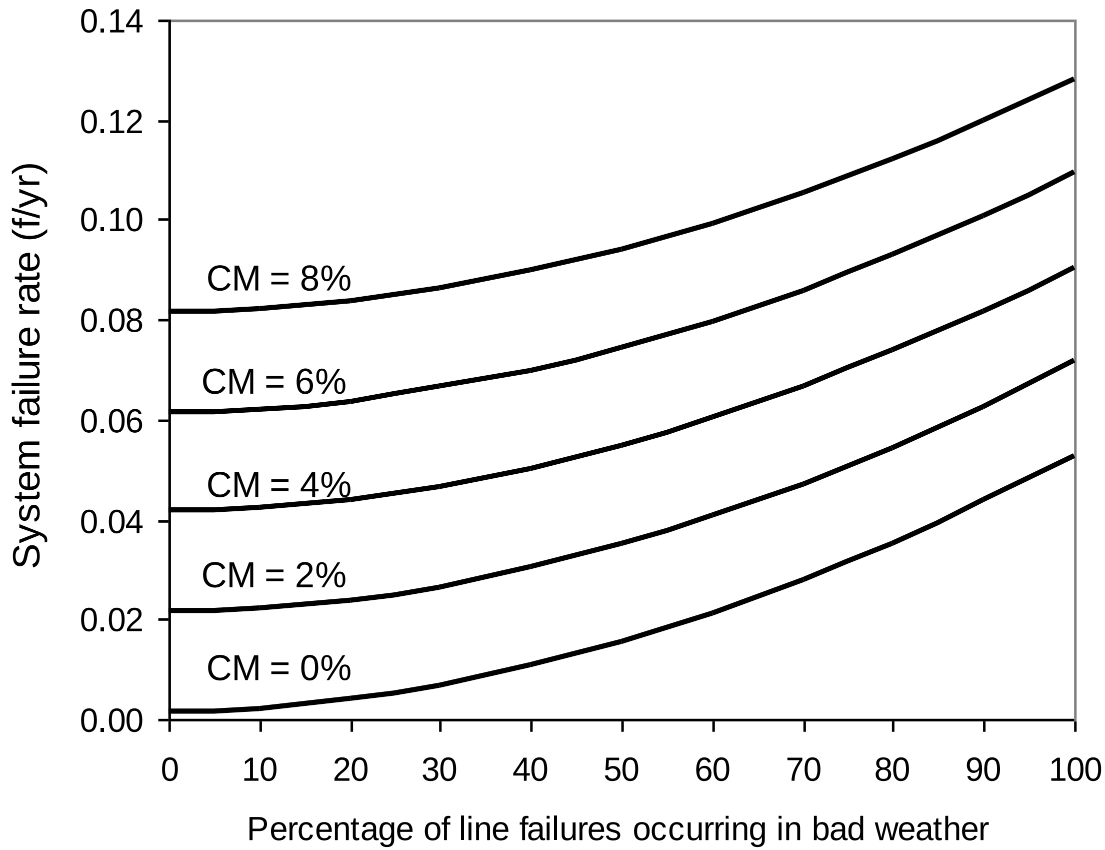
Effect of independent failures and bad weather on the system failure rate with a three-state weather model



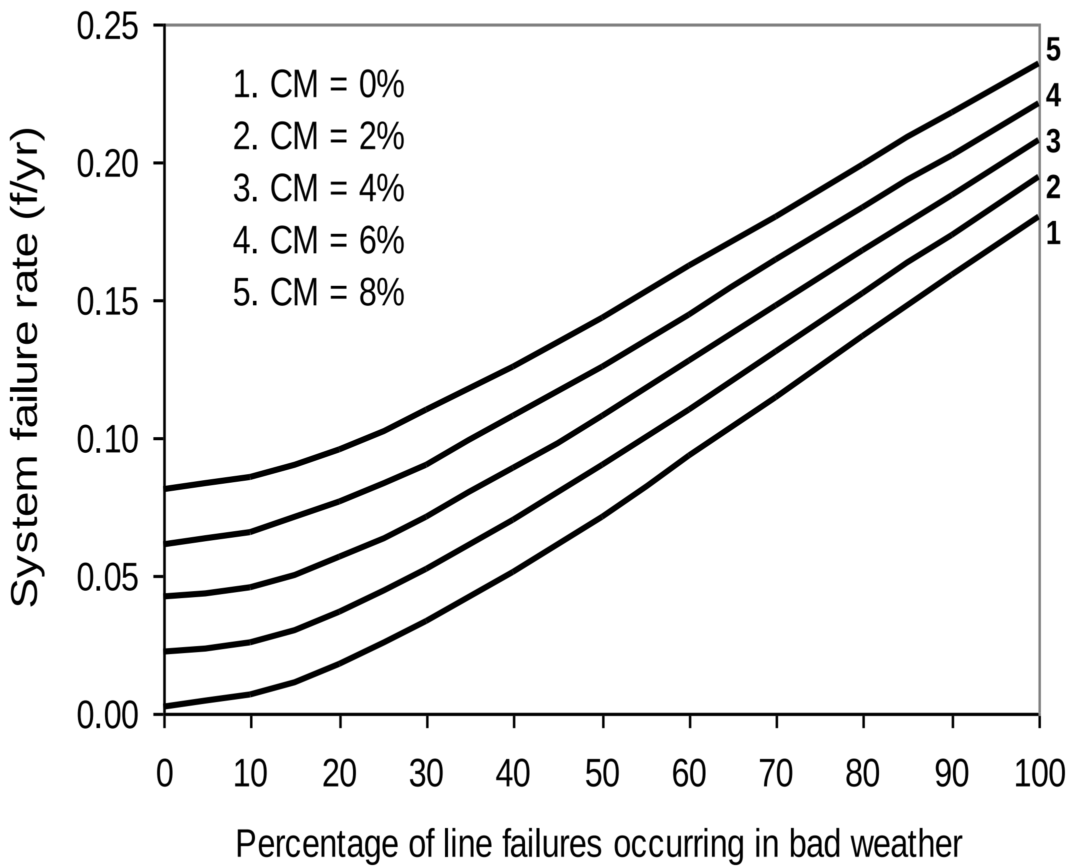
State space model for independent and common mode failures with a three-state weather model



Independent failures, common mode failures and bad weather using a three-state weather model with 10% of the bad weather failures in major adverse weather



Independent failures, common mode failures and bad weather using a three-state weather model with 50% of the bad weather failures in major adverse weather



A dependent outage is an event which is dependent on the occurrence of one or more other outages or events.

Independent failure of one of the circuits in Fig. 1 causes the second circuit to be overloaded and removed from service. It should be noted that while the second circuit is on outage or out of service, it has not failed and cannot be restored by repair action on the line. The outage duration is related to system conditions and operator action.

A similar situation exists when a circuit breaker in a ring bus fails to ground (active failure) and is isolated by the two adjacent circuit breakers. The actively failed component is isolated and the protection breakers restored. Assuming that the two system elements adjacent to the faulted circuit breaker are transmission lines, they would be removed from service by breakers tripping at the other ends of the lines. The lines are on outage but have not physically failed. This is not a common mode failure.

Station originated events require individual station analysis and are directly related to the station topology and design. The outcome of such an analysis is the recognition of a group of possible multi-element outages (removals from service) due to single element failures in the station

The durations of the multi-element outages are usually dictated by the station topology and possible switching actions not by repair of the failed element.