Overview of Common Mode Outages In Power Systems

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Defintions

- A common mode outage refers to simultaneous outages of multiple components due to a common cause.
- IEEE Standard 859 defines a common mode event as:

  A related multiple outage event consisting of two or more primary outage occurrences initiated by a single incident or underlying cause where the outage occurrences are not consequences of each other.
- The common mode outages could be momentary or sustained outages.
- The components involved in common mode outages could be returned to service at the same time or at different times.

Significance of CMF

- Consider two transmission lines on common ROW.
- Assume their failure rates are λ_1 and λ_2 respectively.
- Now consider a small time interval Δt.
- Assuming no repair, the probability of both lines failing during Δt because of independent failures is

  $P(\text{independent}) = \lambda_1 \lambda_2 \Delta t \Delta t$
- Now if there is a common mode failure rate λ_c , then the probability of both lines failing because of common mode failure is $P(CM) = \lambda_c \Delta t$.
- The P(CM) can become significant although common mode failure rate may be small compared to independent failure rate.

Significance

- Example : $\lambda_1 = \lambda_2 = 10/yr$
- $\lambda_c = .1/yr$

  $\Delta t = 1$ hr

$$P(\text{independent failure}) = 10 \times 10/(8760 \times 8760)$$

$$P(CM) = .1/8760$$

$$= 100/(8760 \times 1000)$$

So although the CM failure rate is 100^{th} of the independent failure rate, the probability of both components failing due to CMF is higher.

Illustrative Examples of CMF

- A single lightning stroke causing trip outs of both circuits on a common tower
- An external object causing the outage of two circuits on the same right-of-way.
- Simultaneous failure of two or more lines that are in a common corridors or common right-of-way (ROW) subjected to events such as fire or tornados.
- Common ROW is defined by Western Electricity Coordinating Council (WECC) as “Contiguous ROW or two parallel ROWs with structure centerline separation less than the longest span of the two transmission circuits at the point of separation or 500 feet, whichever is greater, between the two circuits”.

Illustrative Examples of CMF

- A further example would be the failure of a transmission tower supporting two or more transmission circuits.
- The WECC identifies weather excluding lightning, fire and human errors as the most prominent causes of common-mode circuit outages (including both common-tower and common-corridor outages).

Common Mode Failures & Weather Related Failures

- Environment related single circuit failures, when circumstances such as adverse weather increase failure rates over a wide area, are conceptually different from common-mode outages.
- Conditioned on the background of increased failure rates, these environment-related failures are independent events.
- However, such adverse conditions may also substantially increase the rate of common-mode failures.
- The study of environment-related outages is thus an integral part of the study of common mode outages.

Common Mode Failures & Weather Related Failures

- One way of making this distinction is to consider two or more primary outage occurrences as part of a common mode outage event if there is a single external “actor”, which interferes with one or more components of each of the outaged system elements. These components may or may not be common to the outaged system elements.
- The presence of a single “actor” is the principal distinction from dependent or cascading outage events.
- In the case of a dependent outage event the cause of the second element’s outage is some consequence of the first outage: low voltage conditions causing a relay miss-operation, failure of a circuit breaker to operate, or simply isolation because the primarily outaged element is the only path connecting the dependently outaged element to the system at one or more terminals.
- In the case of a cascading outage event the second element is also affected by conditions arising from the primary outage, but system loading conditions are an important causal factor and the relay operation which immediately creates the second outage is correct given the loading etc. following the primary outage.

Common Mode Failures & Weather Related Failures

- In the case of some environmental backgrounds such as hurricanes or tornados, there is a room for doubt as to exactly which combinations of events should be classed as common mode and which as environment-related.
- As example whether the localized cyclonic weather system should be regarded as the single “actor”. The current convention is that unless two faults were simultaneous in time and spatially very close together then they would not be classed as common mode.
- However this is principally a question of terminology, and should not cause difficulties when a modeling study is designed with appropriate care.

Overview of Literature

- Two complementary aspects of the development of any reliability technology:
  - The creation of models and methods and
  - Evolution of data reporting and collection needed for such models.
- We will first review the development of models and methods for the consideration of common mode failures
- This will be followed by the review of data reporting and collection efforts to achieve their implementation.

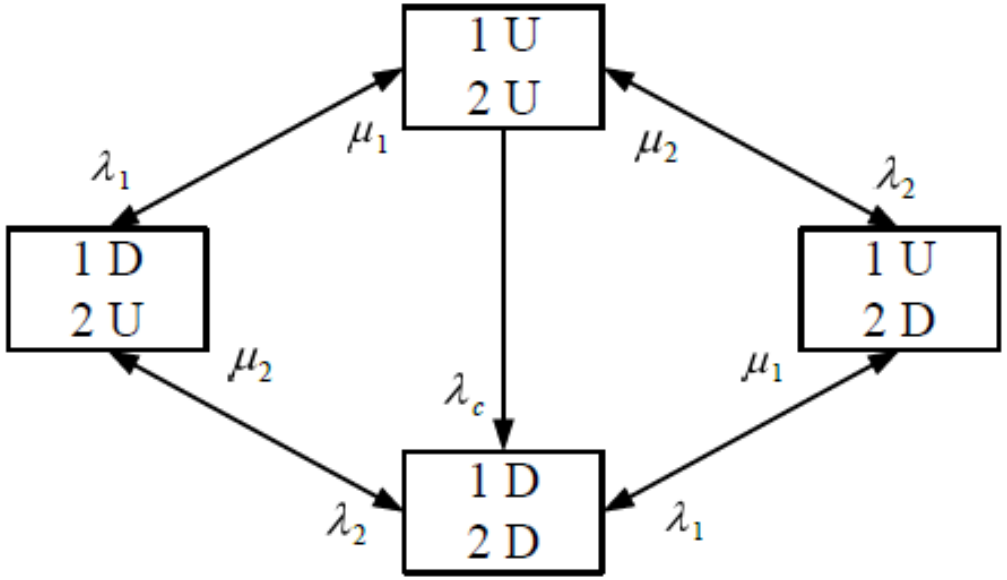
Models and Methods

- Early models of transmission lines assumed independent failures.
- Reference [1] recognized that during the stormy periods the environmental conditions may elevate the failure rates to a much higher level than during the normal weather.
- This would then increase the probability of overlapping failures during adverse weather conditions leading to the failure bunching phenomenon.

Models and Methods

- Importance of common mode failures was recognized in the nuclear power industry and Ref [3] summarizes the state-of-the-art in this industry at that time.
- Common mode failure in this reference was defined as ‘multiple unit failures due to a single cause’.
- In transmission systems, the importance of common mode failures was later recognized and a task force of the Application of Probability Methods Subcommittee proposed the definition and a model of the common mode forced outages of overhead transmission lines in [4].
- A common mode forced outage was recognized as ‘an event having a single external cause with multiple failure effects, where the effects are not consequences of each other’.

Models and Methods



λ_i, μ_i : independent failure and repair rates of component i

λ_c : common-mode failure rate

i U, i D : component i up, component i down

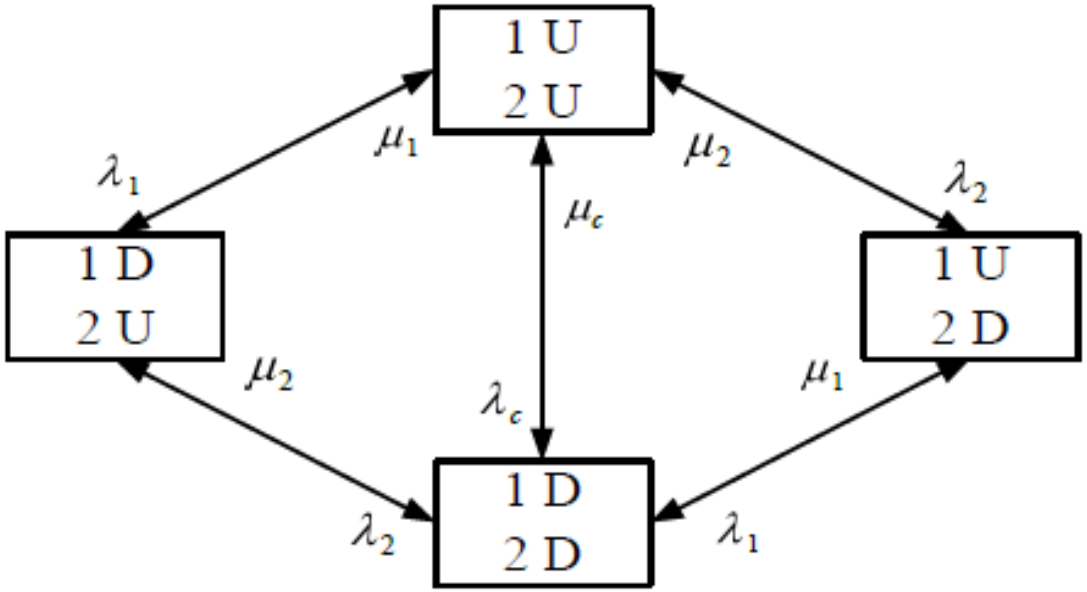
Fig. 1 State transition diagram of a 2-component system indicating independent failures and repairs and common mode failure.

Models and Methods

- Outage causes in this reference were categorized either as natural events or interferences.
- Listed under natural events were fire in the right of way, foundation or anchor failure and severe environmental conditions such as hurricane, tornado and icing.
- Interference could come from other power circuits, aircraft or rail and road vehicles.

Models and Methods

- Later some argued that there should also be a common mode repair in the IEEE model and proposed a model [13] shown in Fig. 2.
- Reference [13] also argued that overlapping failure state reached by common mode events should be considered distinct from that reached by independent failures, and proposed models of the form shown in Fig. 3.
- There may be a difficulty in its use in this particular model. Once state (1D, 2D) is entered, the model cannot distinguish whether the state was entered because of common mode failure or independent failure. There are three repair rates trying to take the system out of this state, $\mu 1$, $\mu 2$ and μc .
- In terms of the physical system, this means that there are three independent repair processes or crews in progress, two of these are repairing one line each and third is trying to restore them simultaneously. This appears to be an exaggeration of the repair process.
- If separate common mode repair is to be modeled, perhaps model in Fig. 3(a) is more appropriate since it distinguishes the failed state due to independent and common mode failures.



λ_i, μ_i : independent failure and repair rates of component i

λ_c, μ_c : common-mode failure and repair rates

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Fig. 2. The modified IEEE model.

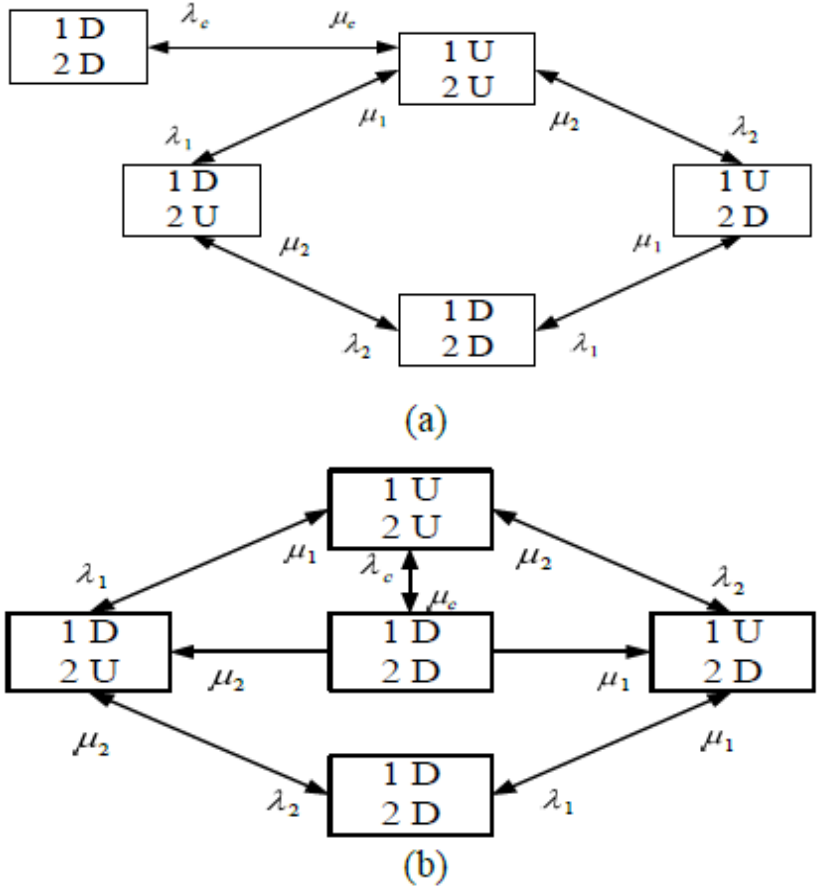
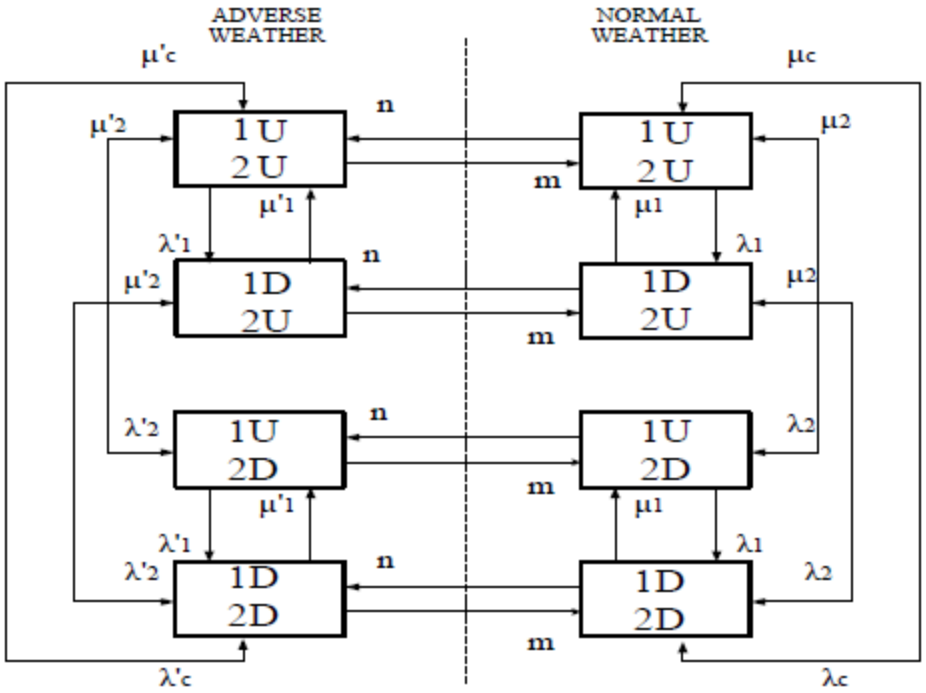


Fig. 3. Alternative models where the common mode failure state is considered distinct from the independent overlapping failure state.



where
the prime indicates the corresponding value under adverse weather, n and m are equivalent transition rates between normal and adverse weathered obtained from the reciprocals of the residence times in these conditions.

Fig. 4. Joint representation of common mode and weather related failures.

Models and Methods

- Considerable difference of opinion exists on how the relative impact of weather related and common mode failures should be handled.
- Although it is understood that during adverse weather the failures may be independent but occur at an elevated rate, in practice it may be difficult to keep their distinction from the common mode failures.
- This is perhaps also a function of how severe the adverse environment is.
- It may be argued that for data collection purposes, the easiest solution may in fact be to recognize multiple failures during the adverse weather as common mode failures.

Models and Methods

- Especially if there is no repair during adverse weather, then the effect of multiple failures during a narrow time window such as 1.5 hours does in fact behave like a common mode failure because the repair time is much longer.
- Using mathematical analysis of equations proposed in [14], it can be shown that recognizing weather related failures as common mode failures will hardly affect the results of these equations.
- Some also argue from physical reasoning that there is an important class of common mode outages in which a localized storm environment is the important feature in common.
- Perhaps these discussions highlight the fact that the definition of common mode failures is open to a diversity of interpretations and a particular interpretation may depend on the intended use of data and models.
- It should be pointed out that this disparity in opinions on common mode failures is not unique to the power systems but is common to the implementation of common mode failures in other fields as well [11].

Models and Methods – Probability Distribution Effect

- With the modeling of dependence caused by common mode failures, an issue that has emerged is that of the probability distributions of state residence times.
- The state residence times of the up and repair states of transmission lines are generally assumed exponentially distributed.
- When steady state analysis is involved and the transmission line failures and repairs can be assumed independent, the probability and frequency calculations are not affected by the form of distributions and so the assumption of exponential distribution is not a material consideration.
- When dependence is introduced between two transmission lines through the common mode failure, the form of distribution can have an influence on the calculated probabilities and frequencies.
- References [6, 18, 22, 24] examine the effect of the distributions when components are subjected to common mode failure and propose methods for modeling when exponential cannot be justified as the underlying distribution.

Outage Data Reporting

- Early literature [36–39] on data reporting does not mention multiple failures due to common mode failure phenomenon.
- In 1981, Reference [40] presented representative line performance data based on Commonwealth Edison's forced outage experience. The paper considered coincident multiple line outages resulting from common mode exposure.
- In this paper, two broad categories were defined first, line related and terminal related outages. Each outage event in a broad category was further classified as independent, common mode or dependent.
- Mid-continent Area Power Pool (MAPP) has been sharing their data collection and analysis efforts through reports and papers. Reference [41] from MAPP includes the consideration of common mode failures. In [44] MAPP and MAIN produced a common format for collection of data.

Outage Data Reporting

- In 1985, an IEEE taskforce [42] provided a definition of common mode failure.
- This reference defined common mode failures as a subcategory of related failures as, ‘a related multiple outage event consisting of two or more primary outage occurrences initiated by a single incident where the outage occurrences are not consequences of each other”.
- It is interesting to note the examples of common mode failures cited in this reference.

Outage Data Reporting

- Examples
  - Trip-outs of two circuits on a common tower.
  - Outage of two circuits on a common right of the way by an external object.
  - Outage of multiple circuits by a tornado even if they are not on a common tower or common right of the way.
- The third example is interesting in the light of discussion on the distinction between the weather related outages and common mode outages.
- It can be seen from the discussions at the end of this paper [42] that there can be a wide disparity of views when it comes to details.

Outage Data Reporting

- As an example, discusser Ludorf suggests the following items to be evaluated when deciding to classify the multiple outages as common mode:
  - The components or units outaged should be as a result of a single cause.
  - Common mode outages will generally be the results of physical proximity, electrical connection such as a common bus or common environment conditions.
  - The outages should be overlapping though not necessarily simultaneous.

Outage Data Reporting

- Examining these statements closely, it can be observed that considerable difference of opinion exists in interpreting whether the outages are common mode.
- Perhaps the two common characteristics are that there is a single cause and the outages overlap to fail the redundancy.
- Several other subsequent publications [43–49] have included the common mode failures in one form or the other.