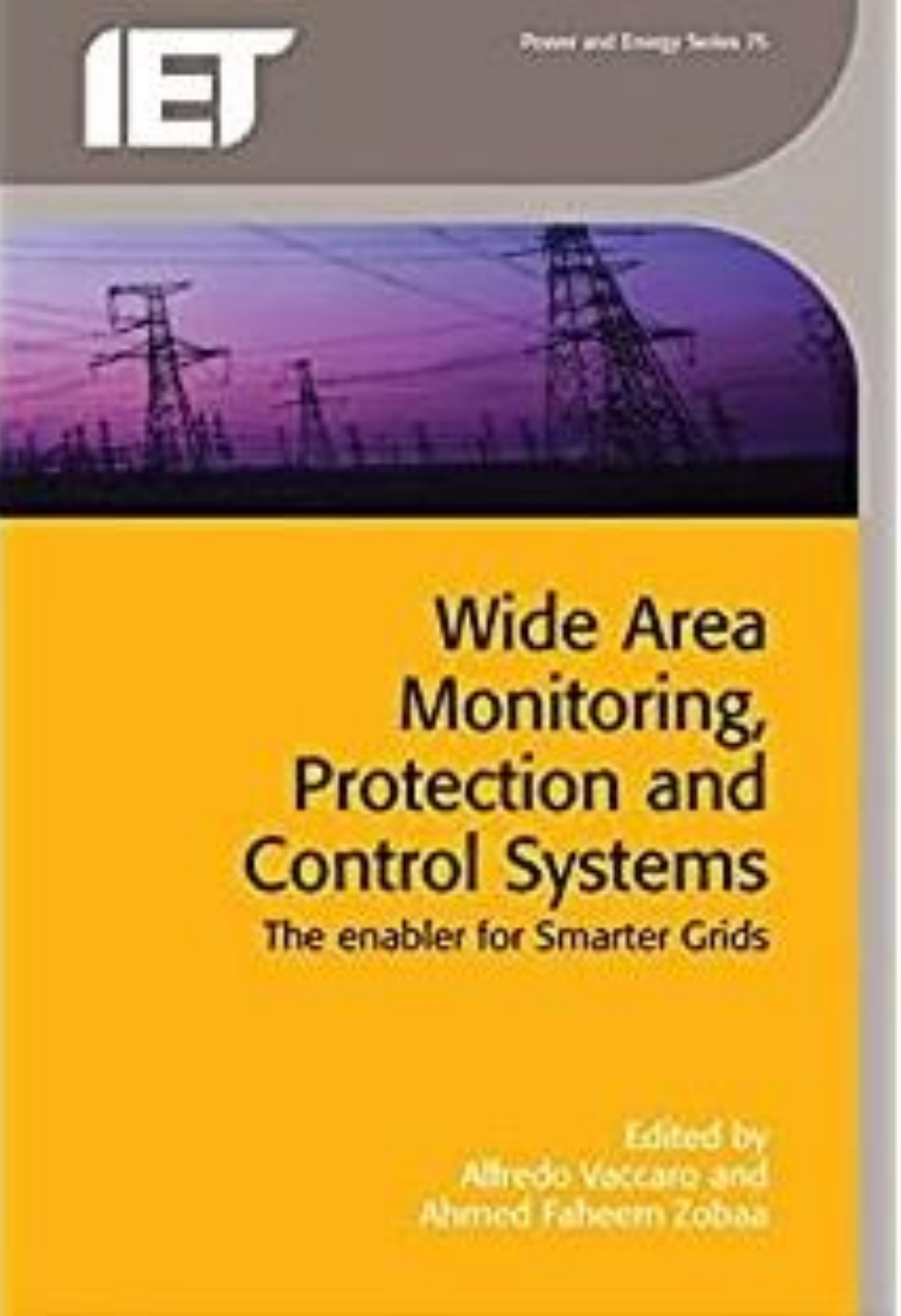


Chapter 2

Reliability-based substation monitoring systems placement

Reliability-based substation monitoring systems placement

- **Substation monitoring system**
  - ✓ Monitoring system components
  - ✓ Branch PMU
  - ✓ Substation configuration
  - ✓ Substation communication system

- **Substation monitoring system reliability**
  - ✓ Failure probability of voltage measurement
  - ✓ Failure probability of current measurement

- **SMS placement based on bus reliability**

- **Reliability-based substation monitoring system placement considering transmission line outages**

- **Evaluation of reliability-based SMS placement**

- **Numerical studies**

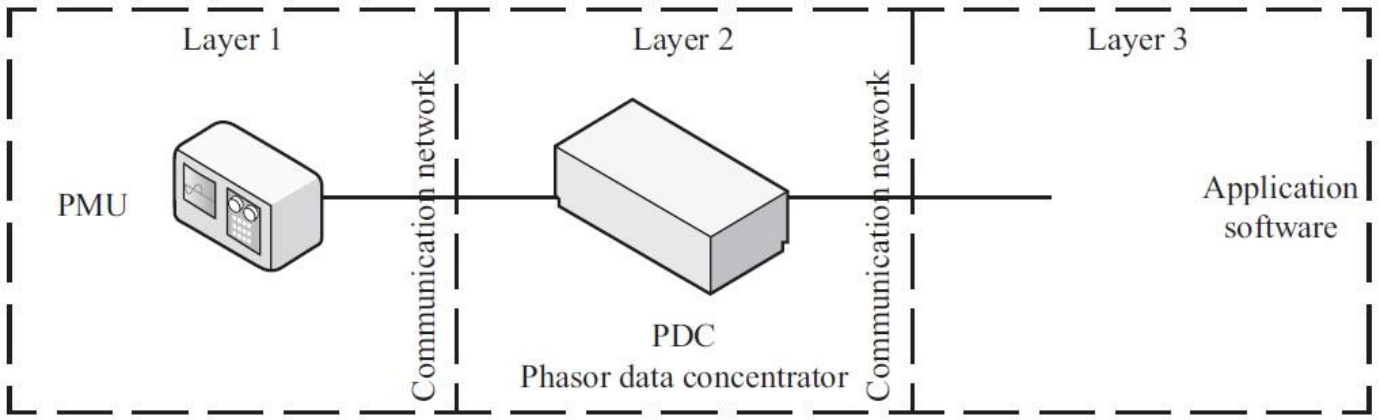
Reliability-based substation monitoring systems placement

Substation monitoring system

Monitoring system components

❖ **An SMS includes four basic components:**

- ✓ PMUs
- ✓ PDCs
- ✓ communication network
- ✓ PMU application software



❖ The first layer represents the interface between the power system and the monitoring system.

- ✓ includes current and potential transformer (CT and PT)
- ✓ wiring to connect the instrument transformers to the PMUs associated with the substation bus bars or power lines.

❖ The second layer contains the substation PDC which collects measurements from PMUs to aggregate and sort them based on the time tag.

❖ The third layer refers to the algorithms and methodologies developed for taking decisions.

▪ Finally, the information transaction between these three layers is realized by the communication network.

Reliability-based substation monitoring systems placement

Substation monitoring system

Branch PMU

- PMUs have infinite number of channels to monitor phasor currents of all branches that are incident to the substation where the unit is installed.

- manufacturers produce PMUs with a limited number of channels to measure currents and voltages, so assuming unlimited number of channels is unrealistic.

- there is another class of devices known as **branch PMUs.**

- These PMUs are designed to monitor a single branch by measuring the voltage and current phasors at one end of the monitored branch.

Reliability-based substation monitoring systems placement

Substation monitoring system

Branch PMU

- **Branch PMUs offer benefits like**
  - increasing the reliability of the monitoring system at the substation
  - uniform distribution in the network
  - adaptability to deployment in multiple stages
  - higher reliability

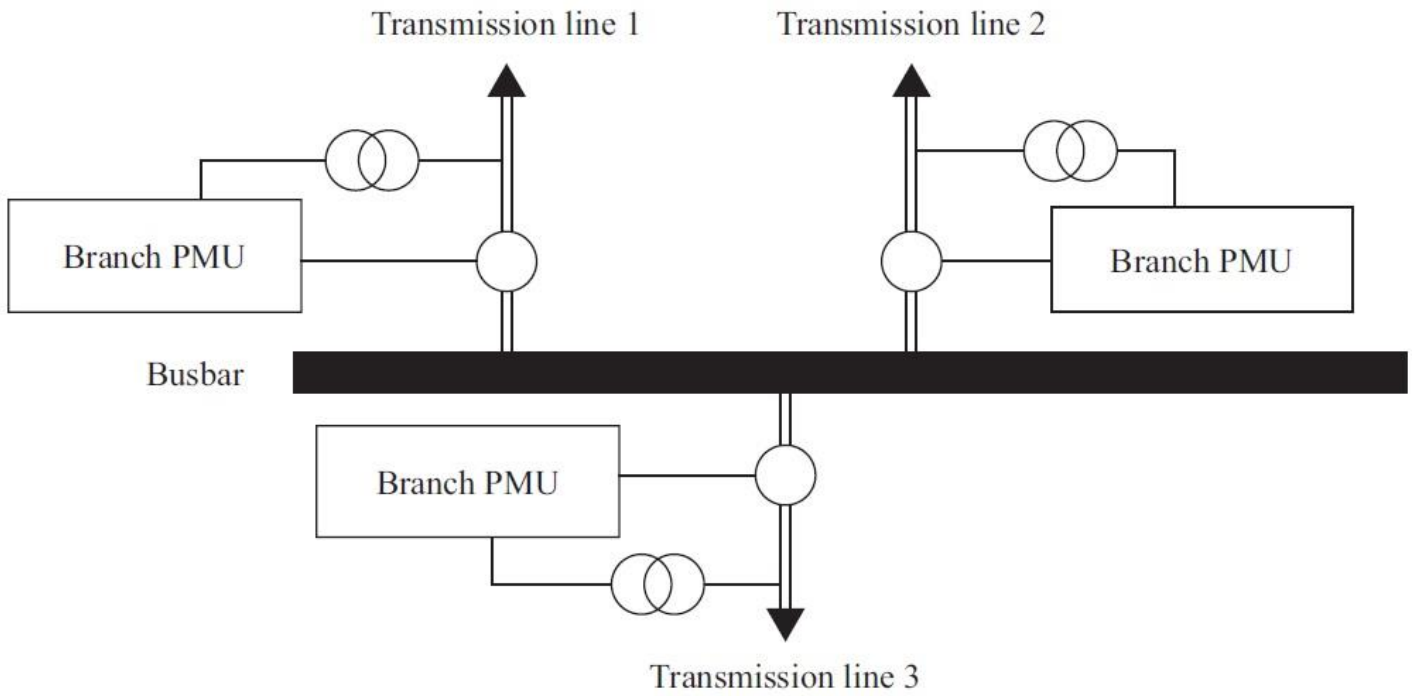


Fig. Branch PMU location at a single busbar substation

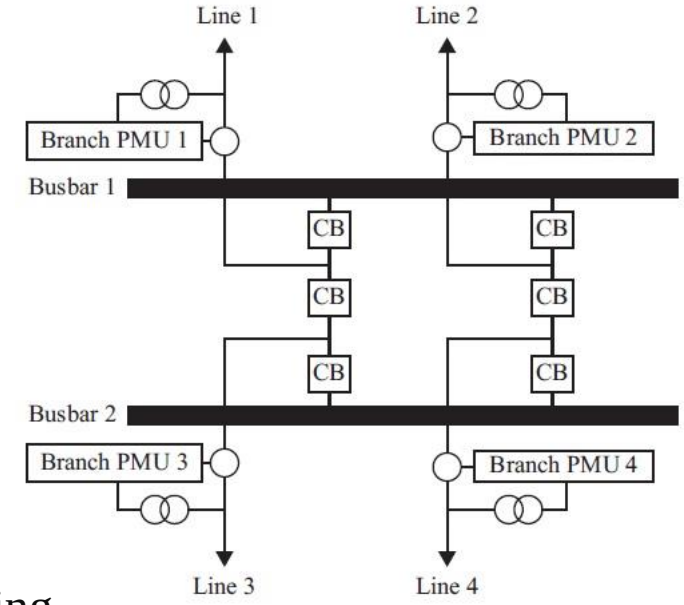
Reliability-based substation monitoring systems placement

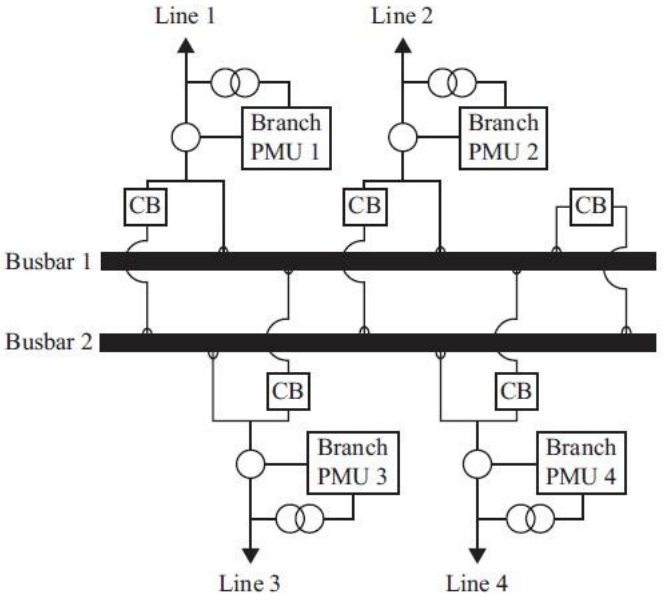
Substation monitoring system

Substation configuration

- Most substations at the transmission system are organized similarly to one of four standard configurations, which are referred to as busbar configurations.

- the basic four busbar configurations are:
  - breaker-and-a-half
  - double-bus-double-breaker
  - double-bus-single-breaker
  - ring bus.





- the number of components in layer 1 of the monitoring system depends on the number of transmission lines; it does not depend on the substation configuration.

Fig. Layer 1 for two substations with different configurations (breaker and- a-half and double-bus-double-breaker)

- **the reliability analysis at each substation will be performed taking into account the number of transmission lines outgoing from the substation.**

Reliability-based substation monitoring systems placement

Substation monitoring system

Substation communication system

❖ **communication system**

- The local communication systems
  - ✓ The local communication consists of links between the instrument transformers, PMUs, and PDC at the substation.
  - ✓ The local communication is responsible for collecting and carrying the information to the PDCs.
  - ✓ This information will be sent posteriorly to regional or national control centers through the wide area communication system.
- interstation communication systems

Reliability-based substation monitoring systems placement

Substation monitoring system reliability

- The first step in designing a reliable WAMS is to assess the monitoring system reliability at each substation; it will be done by using FTA.
  - which is a deductive failure analysis where an undesired state of the system is analyzed using Boolean logic to combine a group of lower-level events.

- The objective of the SMS is to collect the electrical measurements and sending them to the regional or national control center ;
  - therefore, the undesired effect (the top event) is defined as losing observability of the substation.

- The situations that could cause losing observability of the substation are:
  - ✓ impossibility of getting voltage or current measurements
  - ✓ failure of the PDC
  - ✓ failure of the local communication system.

Reliability-based substation monitoring systems placement

Substation monitoring system reliability

- When PMUs with several channels are used and a fault occurs in the PMU, this fault will affect the entire SMS.
- in case of branch PMU, the failure of one branch PMU will not affect the measurement of the voltage or current.

- $\mathbf{Q_{sub\ i} = 1 - ((1 - Q_{mea}) \cdot (1 - Q_{pdc}) \cdot (1 - Q_{com}))}$
- $\mathbf{Q_{mea} = 1 - ((1 - Q_{vm}) \cdot (1 - Q_{cm}))}$
- $Q_{sub\ i}$ is the failure probability of the monitoring system at substation i
- Q_{mea} is the failure probability of the measurements
- Q_{pdc} is the failure probability of the PDC
- Q_{com} is the failure probability of the internal communication system.
- Q_{vm} is the failure probability of the voltage measurement
- Q_{cm} is the failure probability of the current measurement.

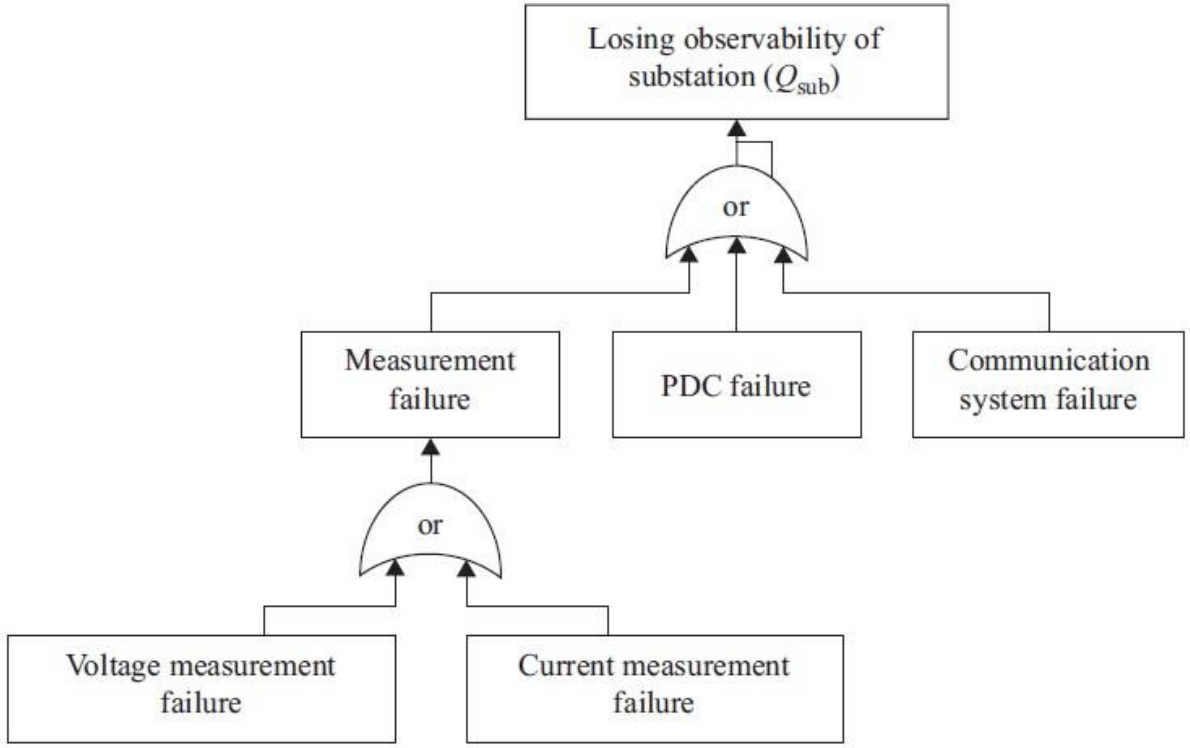


Fig. FTA model of an SMS

Reliability-based substation monitoring systems placement

Substation monitoring system reliability

Failure probability of voltage measurement

❖ Branch PMUs are designed to measure the voltage and current phasors at one end of the monitored branch

- each branch PMU installed at the substation can measure the voltage phasor.

❑ $Q_{vm} = 1 - \prod_{j=1}^{N_{1b}} (1 - Q_{V_{bay_j}})$

❑ $Q_{V_{bay_j}} = 1 - ((1 - Q_{pt_j}) \cdot (1 - Q_{pbmu_j}) \cdot (1 - Q_{plink_j}))$

- Q_{vm} is the failure probability of the voltage measurement.
- $Q_{V_{bay_j}}$ is the failure probability of the voltage measurement at the line bay j
- N_{1b} is the number of j outgoing line bays in the substation.
- Q_{pt_j} is the failure probability of PT at line bay j
- Q_{pbmu_j} is the failure probability of the branch PMU at line bay j
- Q_{plink_j} is the failure probability of link between the instrument transformers and the branch PMU.

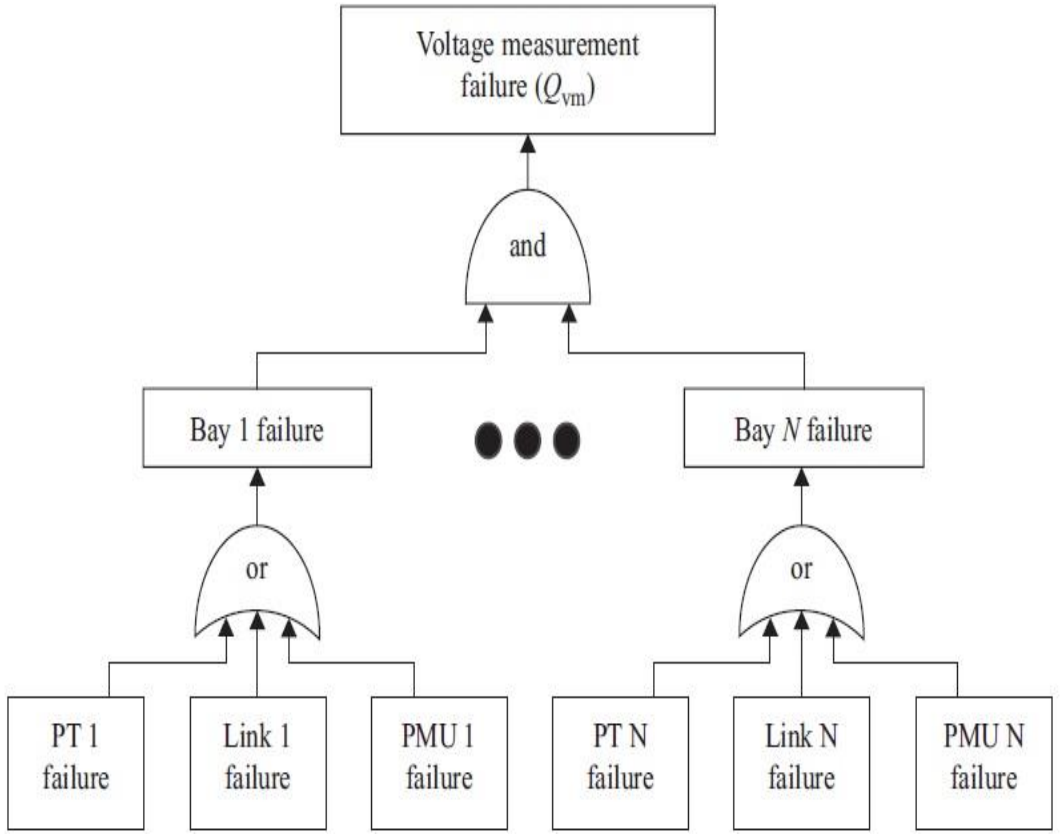


Fig. FTA model of voltage measurement

Reliability-based substation monitoring systems placement

Substation monitoring system reliability

Failure probability of current measurement

- The current measurement cannot be obtained when two or more measurements at the line bays fail
  - If one branch PMU fails, the current in the transmission line, where the failed branch PMU is located, can be estimated in the PDC using the other current phasors and the Kirchhoff laws.

- the failure probability of the current measurement can be determined by calculating the probability that two or more of N_{1b} current measurements fail.
- The current measurement at a line bay could fail if the CT, the branch PMU, or the link between the instrument transformers and the branch PMU fail

- It is important to point out that the branch PMU would require three phase values for calculating the positive sequence, so the outage of one PT or CT in one of three phases would render the PMU unable to measure the voltage phasor.

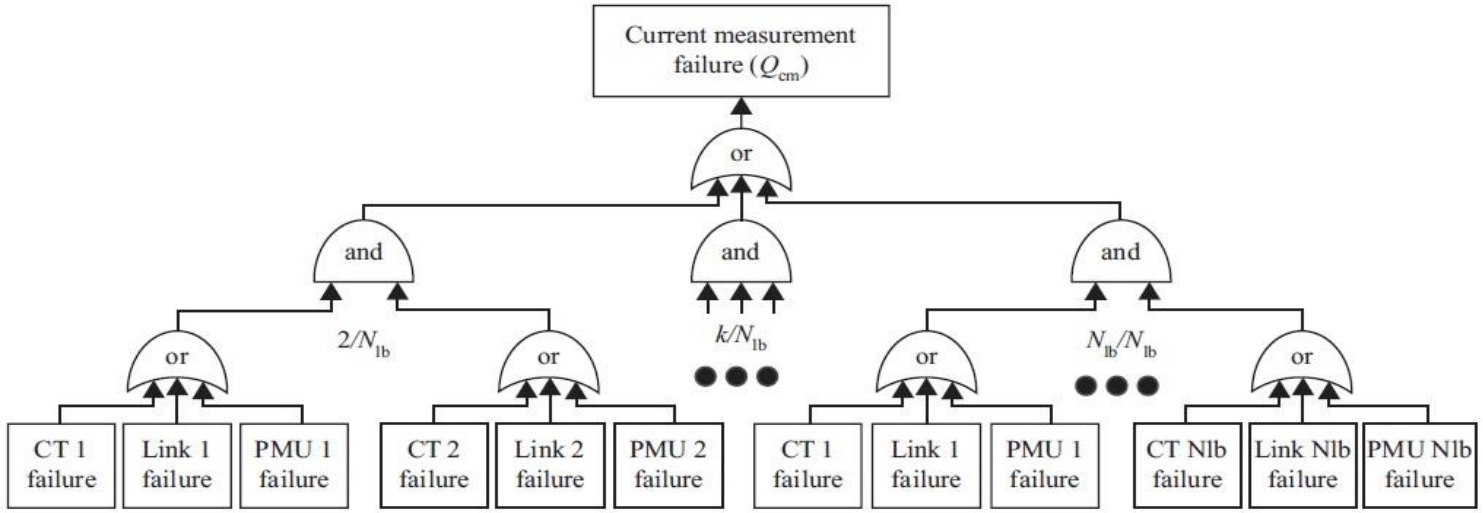


Fig. FTA model of current measurement

Reliability-based substation monitoring systems placement

SMS placement based on bus reliability

- The first step in evaluating the reliability of WAMS is to assess the SMS reliability based on the availability of its basic components.
  - from the standpoint of the location in the power system, not only the availability of the SMS but also the availabilities of the transmission lines are necessary for the proper operation of the WAMS.

- According to the number of circuits between buses, transmission line failures can be modeled as a single component which can have either in service (up) or out of service (down)

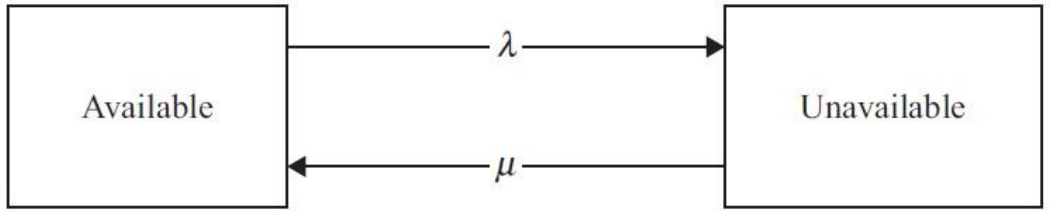


Fig. Model of a transmission line as a single component

- A two (or more) repairable independent components with independent and common mode outages.

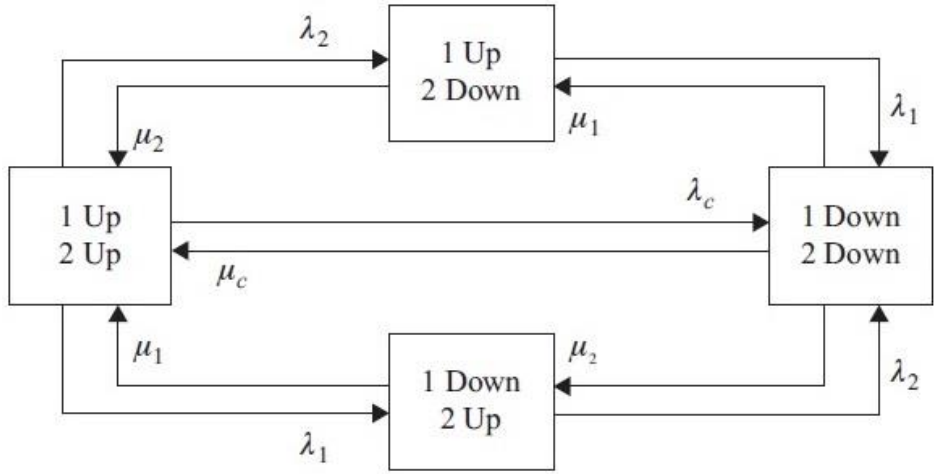


Fig. Model of a transmission line as a two component

- $R = \frac{\mu}{\lambda+\mu}$
  - **R : the probability that the transmission line is in service**
  - **λ and μ : the failure and repair rates**

Reliability-based substation monitoring systems placement
considering transmission line outages

- The SMS placement must be robust enough to maintain system observability anticipating possible transmission line outages

- therefore, a reliability-based linear optimization model for the SMS placement should be developed in order to identify the most credible contingencies to be taken into account for the SMS location, that is, contingencies that have relatively high probab ility.

- he proposed model strategically places an optimal number of SMSs to monitor the power system under normal operation and the single component contingencies that have high probability.
  - In order to identify the most probable contingencies, state space enumeration technique is used.

- This method involves defining all possible single component contingencies states of the system based on the states of the transmission lines.
  - A state is defined by listing the successful and failed transmission lines in the system. The states that result in successful WAMS operation are identified, and the probability of occurrence of each successful state is calculated.

- **The reliability of the WAMS can be calculated as the sum of all the successful state probabilities.**

Reliability-based substation monitoring systems placement

Evaluation of reliability-based SMS placement

- indexes will be computed to evaluate the robustness of any monitoring system placement solution.
  - The first two indexes are based on the reliability of the SMSs and the single component contingencies considered for observability by the WAMS
  - denominated average probability of observability (APO)
  - the failure probability of WAMS caused by a failure in a substation or a single line contingency not considered for observability.

- A contingency considered for observability means that the power system is still observable under this contingency.

- A contingency not considered for observability refers to the case where a transmission line or branch contingency causes loss of observability.