

## 2.4 (n-1)-Principle - Redundancy

### Target of the utility:

- offering a high reliability level to supply the customers
- minimisation of the internal network costs
- > optimum of the total costs.

### Mathematically:

Minimum of investments considering the condition of (n-1)-principle

### Definition of (n-1)-principle:

One faulty unit/component doesn't lead to a following overload, fault or outage of another unit/component in the regarded network.

(n-1): historical; long before the expression "reliability/availability" has been used and calculation methods have been developed.

### Difference between probabilistic and deterministic (n-1)?

method	analysis instrument	planning target
deterministic	load flow, outage simulation	(n-1), (n-x), network reserve
probabilistic	reliability calculation	limits of system reliability, financial valuation of measures

### System reliability characteristics:

- expected frequency of interruptions /customer [SAIFI]
- expected duration of interruptions /customer [SAIDI]
- expected probable condition of outages
- expected interrupted power (NDP)
- expected non-delivered energy (NDE) /customer [ASCI]
- average system availability/customer [ASAI]

### Probabilistic planning

- prognosis of the future behaviour of the network
- using quantitative experiences from the past
- outage lists
- considering the occurrence probability, the typical kind of outages and the rate must be known; in Germany we have the VDEW outage and damage statistics.
- resupplying models need information about local situations as automatic

- switch-over devices, the activating time, repair time ...
- data precision is very important
- analytic methods or Monte-Carlo-simulation
- workstations are sufficient for calculations

### Calculation:

- calculated all outage states
  - (1) without interruption of customers, load limits are not crossed
  - (2) without acceptable interruptions (customer consequences grave, frequency)
  - (3) with bad interruptions (economical reasons, catastrophic events)
- > definition of an acceptable limit between (2) and (3)

### Consequences if planning is done only with probability calculations?

- definition of accepted availability index
- analysis of all possible/useful network solutions
- comparing investments/annual costs with the availability index
- argumentation against customers, if a line has to be switched off because of maintenance reasons.

### (n-1)-planning

- definite level of availability is underlayed (risk during (n-0) availability)
- no limitation of interruption duration and frequency
- interruption duration is limited to the switch-over time
- the acceptable switch-over time depends on the interrupted power
- with the increasing NDP the acceptable time for switching over decreases, assumed that the NDE is comparable (automation, doubling, systems, ...)
- with decreasing NDP, possibility of switch-over can be omitted if repairing time is shorter than acceptable interruption duration (LV network)
- investigation of network details, optimising the cost/benefit relation ->
- cost optimised (n-1)-network
- calculation of all possible combinations of component outages means theoretical  $2^{n-1}$  variants,
- therefore pre-selection of the most critical combinations of network elements.
- assumption, that
  - the stochastic events and the outage consequences are independent
  - availability characteristics of the elements are of comparable dimensions
  - the outage duration is relatively short (attention !!)
  - the outage frequency is small

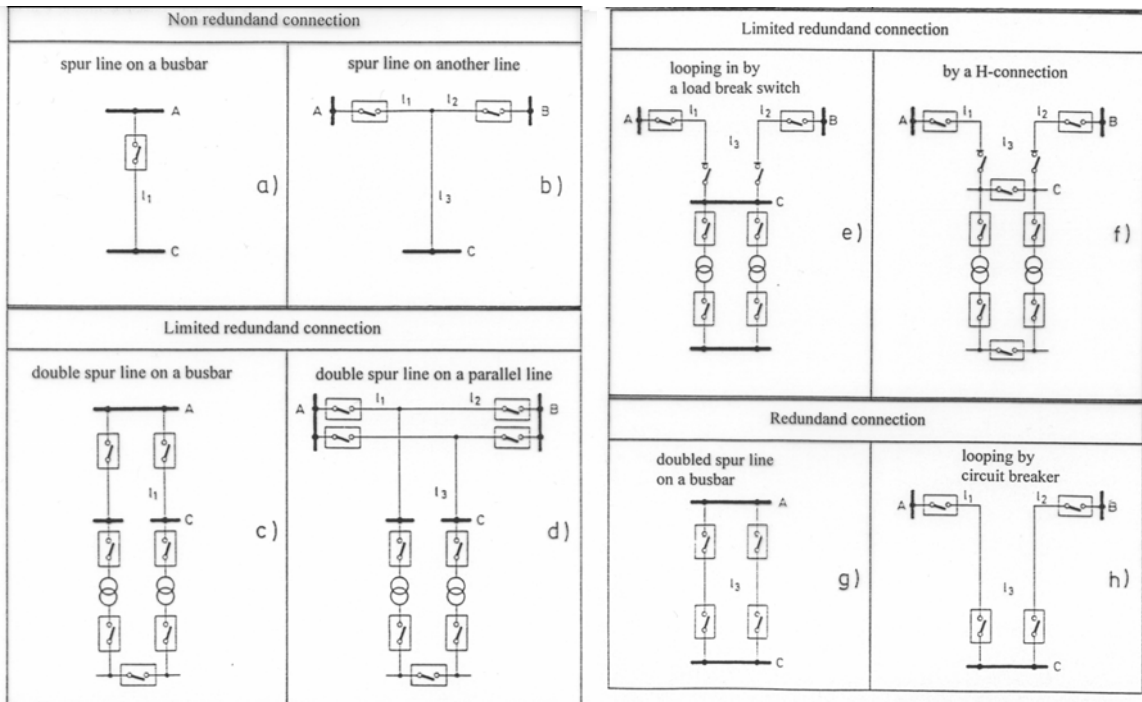
In principle an analysis with the availability program can be conducted if the outage

list is restricted on the (n-1)-variants. In this case no interruptions are allowed.

**Consumer orientated valuation:**

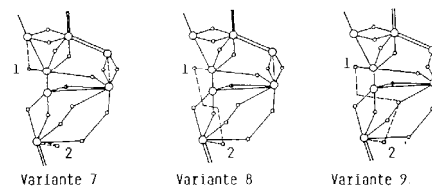
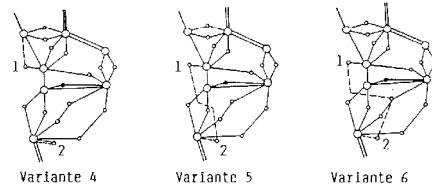
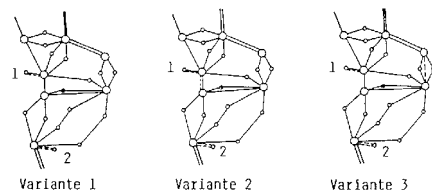
- (n-1)-principle as a general planning criterion considering the peak load of the network
- considering interruption duration and frequency.

<i>Steps of analysis</i>	<i>Probabilistic - availability - calculation</i>	<i>(n-1)-principle network analysis</i>
determination of an outage list	probabilistic and/or deterministic	always 1 unit/component
network state analysis	load flow	load flow
considering determined following outages	automatically by protection models	manually by analysing load flow results
identify the supply status, ration of power	automatically by load shedding models	manually by analysing load flow results
finding out of interruptions	automatically by analysing the power-rationing	manually by analysing load flow results
Re-supplying	automatic by re-supply models	-----
documentation of statistics	automatically with statistic methods	manually (not necessary in (n-1)-systems)
results	system availability, characteristics, load flow results, re-supplying running	load flow results
valuation	probabilistic, deterministic, mixed	(n-1) : satisfied yes - no



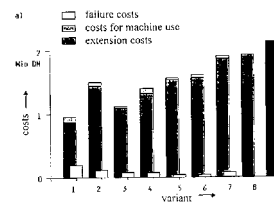
Extended (n-1)-principle  
network planning

- all network elements available
- annual peak load
- load flow for checking (n-1)-principle



Different variants of network extension on condition that all nodes are double-linked and the failure risk will be reduced.

1; 2 transformer stations

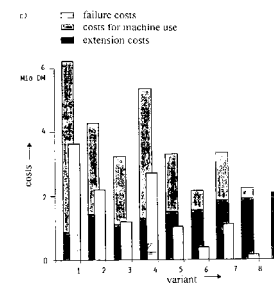
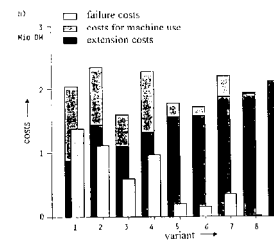


Comparison of the variants relating to the annual costs in case of different power-loads.

a) power load: 0,5 up to 1,0 p.u.

b) power load: 0,56 up to 1,13 p.u.

c) power load: 0,63 up to 1,25 p.u.



**operational planning - an additional decision criterion -**

- o minimum 1 element is switched off
- o actual load and power plant availability
- o simulation of load flow considering the outage of the critical elements ((n-2)!)
  - o accepted short time overload of elements (120...140%)
  - o counter measures
    - changing the power injection points
    - shifting the switching-off of elements
    - measures to be able to re-switch the elements being switched off.
- o critical faults are more probable during maintenance or repair measures than during undestroyed operation
- \* definition of operational switching-off possibilities (transformers, busbars partly, cables, lines, .. )
- \* finding out critical load by load flow calculation that will initiate following outages by the protection system
- \* calculating the probability of outages during the time of one switched-off unit, considering the arranged load duration shape
- \* adding all probabilities concerning the switching-off of other elements
- \* comparing the sum-probabilities of outages for different network extension measures as
  - **additional decision criterion -**