Probabilistic approach in modeling and simulation

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Summary

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Introduction

Probabilistic methods in power systems

- Applications: the following topics illustrate areas in which probability methods have & are being applied.
  - Short-circuit analysis
    - Fault location, fault type, system conditions.
  - Transient stability
    - Location of disturbance, injected power, fault type, fault clearing type, system impedance, system conditions.

Ongoing developments

- Load Flow
  - Power injetion, loads, generation, network configuration.
- Reliability assesssment
  - Generation capacity, loads, renewable generation, network configuration.

Widely developped methods

Probabilistic methods in power systems

- Probabilistic approach ➔ power system reliability
- Reliability
  - Adequacy : generally considered as the existence of sufficient facilities within the system to satisfy the consumer demand.
  - Security is considered to relate to the ability of a system to respond to disturbances arising whithin that system.
- Reliability evaluation ➔ power system planning studies

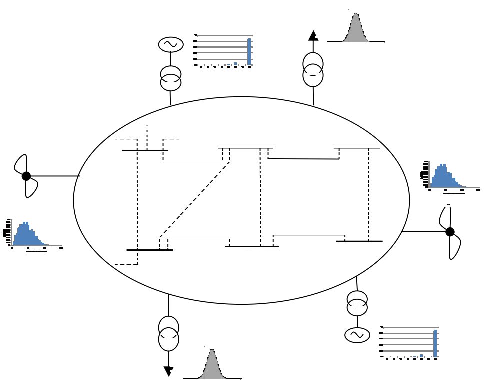
Power system planning

- Operational planning refers to studies related to at most a one year time window from the present.
  - Day to day operation of the system
- Transmission and generation planning: simulations are performed to look at extreme system conditions over many years while considering future load growth.
  - System upgrade

Power system planning: Main issue

- Quantify the risk assiciated with contingencies in a power system both within the operational and the transmission/generation planning horizon.
- How this risk may impact the reliability, security and stability of the system?

Power system planning: two approach



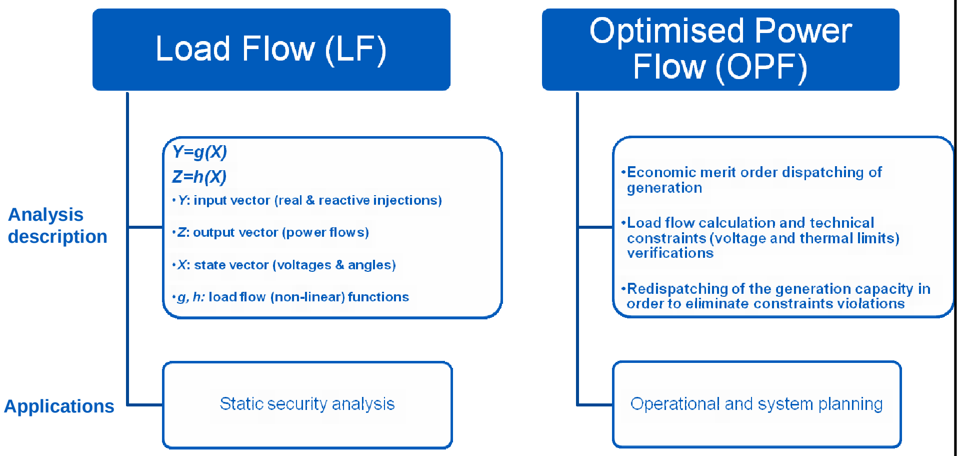
- Deterministic approach
  - Parameters ➔ fixed values
  - Optimised Power Flow (OPF) simulation of a set of system configurations (e.g.: worst cases)
- Probabilistic approach
  - Parameters ➔ probability laws or time series
  - OPF simulation of a large number of system configuration, representing the system behavior during the study period.

Deterministic approach

Deterministic model

- Steady state system model
  - Snapshot of the system operation corresponding to a specific instant in time
- Data:
  - Active and reactive power consumed by each load
  - Power generation and voltage magnitude at the generation buses
- Used to carry out classical security and stability analysis wich are based on **load flow** calculations

Deterministic analysis : basics

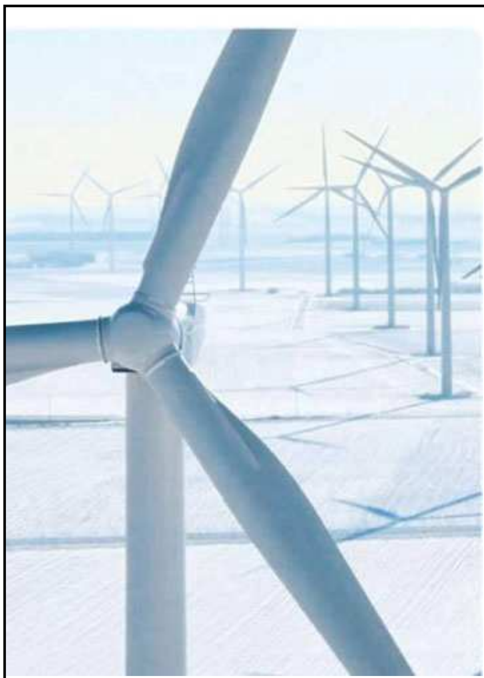


Deterministic analysis : Methodology

- « Worst cases » situations selection
  - Maximum an minimum load situations for example
  - Other network contigencies identified as most restricting
  - Generation schedule
- Deterministic criteria indentification
  - Installed capacity equals the expected maximum demand
  - Spinning reserve capacity equals the largest unit capacity
  - N – 1 criterion
- Simulations
  - Perform a simulation on the events, and identify any that violate the performance evaluation criteria

Deterministic analysis : weaknesses

- The deterministic analysis does not reflect the power system variations.
  - Uncertainties due to load and renewable generation variatins are not taken into account;
  - Unequal probabilities of events leading to potential operating security limit violations is not evaluated.
    - For example the N – 1 approach would not differenciate between a 10 km line supplying a highly meshed network part and a 200 km line supplying a less meshed load center.
- Designing the system on worst cases basis ➔ wrong investment decisions
  - The worst case may be missed, and the violation may occur even at a « non-worst » case operation condition.
  - Overinvestment



Probabilistic approach

Why?

- Previously (deterministic approach):
  - uncertainty was handled by increasing redundancy
  - Question: « how much redundancy at what cost? »
  - Leads to overinvestment (oversizing)
- Power systems are complex and have an uncertain behavior due to variable parameters
- Main sources of uncertainty in power systems:
  - Variability of load (amount, type, characteristics),
  - Network components availability,
  - Conventionnal generation availability,
  - Variability of renewable generation,
  - Enviroment – that is weather conditions,
  - Economics and market.

☛ Probabilistic analysis

Probabilistic analysis

- Probabilistic load flow (PLF): problem formulation
  - Given:
    - The network topology (*n* buses of which *m* load buses, *l* lines) and the lines' parameters
    - Probability density functions (PDF) of active injections at all nodes of the network and probability density functions of reactive injections at all the load nodes
  - Calculate:
    - The mean value, standard deviation and probability density functions of active and reactive injections, active and reactive flows, voltage at load nodes and angles.
- Two approaches for probabilistic analysis:
  - Analytical (mathematical) method
  - Simulation method

Probabilistic analysis: analytical methods

- Calculate PDF of ouput
  - By complex mathematical equations which result from linear approximations of load flow equations.

- Calculation methods
  - Linearisation of load flow equations around a functionning point
  - Convolution (normal independant variables)
  - Cornish-Fisher expansion (consideration of linear correlations between input variables)

- Limitations
  - Non linearity of the load flow equations (OPF includes more non-linearity due to redispatching of generation)
  - Complex statistical dependency of input variables
  - Non parametric probability law representing input variables

Probabilistic analysis: simulation methods

- Probabilistic modeling of the power system
  - Inputs PDF
  - Dependence structure

- System configurations generation according to the probabilistic model
  - Monte Carlo random sampling,
  - Monte Carlo sequential sampling (time series generation).

- System configurations simulation

Probabilistic model

- Representation of all varying parameters by:
  - Probability laws
  - Time series

- Varying parameters :
  - Load,
  - Network components availability,
  - Conventional generation capacity,
  - Renewable generation.

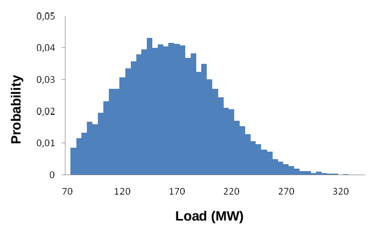
Probabilistic model: load

Time series

- obtained by applying the consumption growth rate on historic load records

Probability law

- Transformation of time series into distributions (for example one year of hourly measurements in the figure)



Probabilistic model: network availability

- Lines availability can be estimated based on:
  - Historic records
  - or empirical formulas: it depends mostly on the line length and structure (number of cables; e.g. the following formula, applied for 90kV lines, where *L* is the line length and *n* is the number of cables)

$$P = (1.8n + 0.1L)10^{-4}$$

Probabilistic model: Probability law of generation capacity

- Two approaches :
  - Basic probability methods only take into account the failures rate of the differents generation units

$$F(X) = \sum_{i=1}^{n} p_i F'(X - C_i)$$

  - Frequency duration methods which also take into account the units' transition rates.

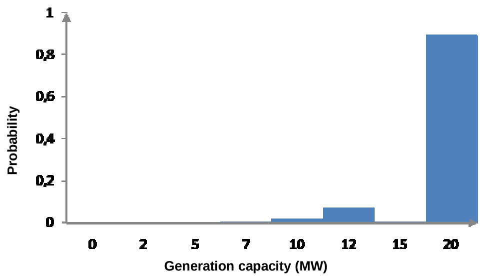
$$p(X) = \sum_{i=1}^{n} p'(X - C_i)p_i$$

$$\lambda_+(X) = \frac{\sum_{i=1}^{n} p'(X - C_i)p_i\left(\lambda'_+(X - C_i) + \lambda_+(C_i)\right)}{p(X)}$$

$$\lambda_-(X) = \frac{\sum_{i=1}^{n} p'(X - C_i)p_i\left(\lambda'_-(X - C_i) + \lambda_-(C_i)\right)}{p(X)}$$

Probabilistic model: Probability law of generation capacity

- Example of results obtained with basic probility methods:



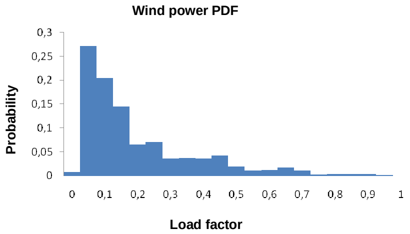
Probabilistic model: wind generation

Time series

- obtained by various complex techniques:
  - Auto-regressives processus (ARMA, ARIMA),
  - Artificial Neural Network,
  - Wavelet techniques.

Probability law

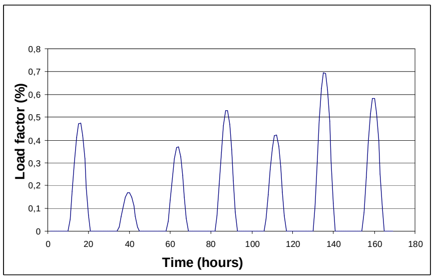
- Calculated for a farm by algorithm taking into acount:
  - Turbines wind-power caracteristics,
  - Wind variation through the farm (smoothing effect)



Probabilistic model: PV generation

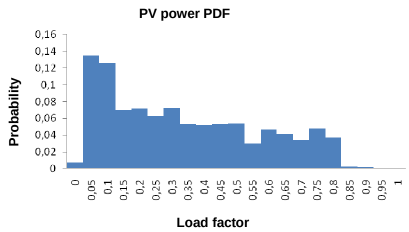
Time series

- obtained by transforming the irradiation time series into power production through the PV farm model



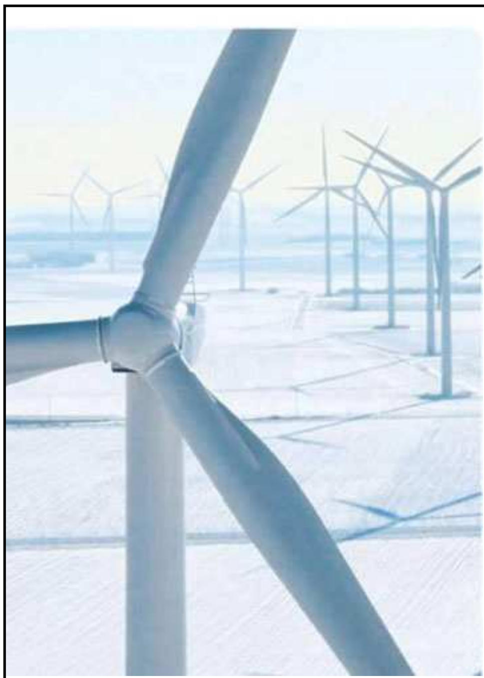
Probability law

- Calculated by transforming of the PV time series into distributions of probability



Probabilistic approach : conclusion

- Methods presentation
- Use of simulation methods for planning studies
  - Analytical methods are limited in handling complex non-linearities involved.
- Power system probabilistic model description



Maximum penetration rate of wind/PV power in an island power system

Methodology

- Calculate the probabilistic model of the system
- Define reliability criteria (ex: probability of voltage violation, line congestion; Probability of not having sufficient reserve; Loss of load probability…)
- Generate a large number of system configurations corresponding to the system behavior during the study period (e.g. one year) and based on the system probabilistic model
- Execute static (Optimised Power Flow – generation dispatch under network constraints) simulations with the system configurations generated above
- Analyse the results, so as to extract the relevant useful information, such as
  - Simulated configurations leading to limit violation
  - Boundaries between dangerous and secure situations and weak points or limit of the system (e.g. maximum penetration rate)
  - Actions to be taken to avoid dangerous situation (e.g. decrease renewable production, add voltage control)
- If all the criteria are respected, increase wind capacity and restart the process.

Tools

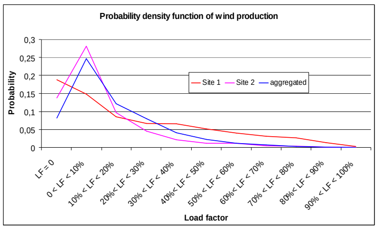
- The software platform ASSESS®
  - Model the uncertainty on system parameters
  - Generate random system configurations which are data for the power system analysis specialized tools like:
    - METRIX®(OPF in DC)
    - TROPIC® (OPF in AC)
    - ASTRE ®
    - EUROSTAG®
- The statistical tool SAS®
  - Used to perform statiscal analysis of simulations results

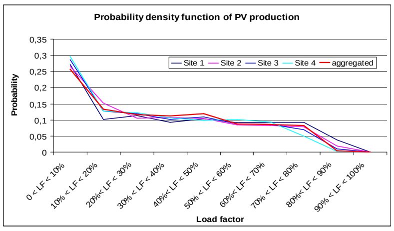
Probabilistic criterion

- Definitions
  - ***Fault***: thermal or voltage limit violation;
  - ***Fault variant***: System configuration which led to a fault;
  - ***Fault rate***: Number of fault configurations divided by the total numbers of simulated configurations.
- Probabilistic criterion définition
  - System fault rate **less than 0.3%** which is the fault rate of the reference system (without new RES).

Probabilistic model

- RES integration hypothesis
  - PV production capacity is two times the wind production capacity
  - Two sites for wind farms and four for PV
- Probability distributions





- Conventional generation units' availability is modeled by the basic probability method.

Simulations

- Simulations consist in:
  - For a given penetration rate, *'OPF'* calculations of all the system configurations obtained according to probability distributions,
  - comparing the fault rate obtained to the criterion
  - and increasing the amount of RES until the criterion is reached.

Results

Variation of the fault rate with the penetration rate

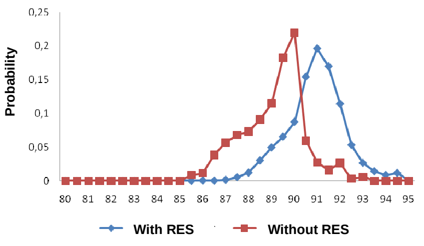
Penetration rate	4% (reference case)	25%	40%
Fault rate	0.3%	0.3%	0.4%

Share of different types of production in % (annual average)

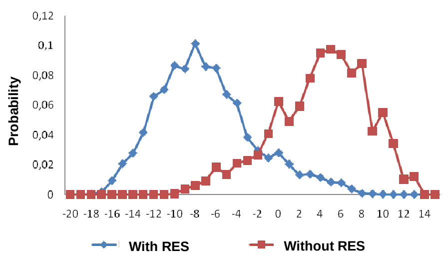
	RES	Diesel	Hydro
Penetration rate 4 %	2	80	19
Penetration rate 30 %	10	73	17

Results

Probability distribution of a node voltage with and without RES

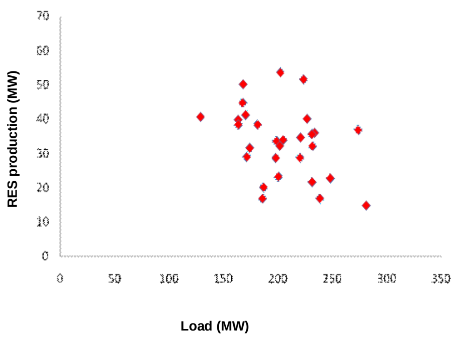


Probability distribution of line transit with and without RES



Results

Simulated configurations (blu) and fault configurations (red)



Case study: conclusion

- Maximum penetration rate calculated considering static security constraints
- Next step: consider dynamic constraints
  - System behavior through the study period after a short-circuit, generation unit outage

Conclusion

- Need to make available more systematic ways of addressing uncertainties in power system modeling and studies
- Probabilistic methods
  - provide the whole power system variations spectrum;
  - Allow variation to be assessed in an objective way
  - Facilitates economic decision making for investment
  - Provide basis for selection of the best alternative over a range of scenarios.
- Data requirements
  - Necessity of significantly large amount of data
  - Extensive data manipulations, processing and analysing
  - Outcomes largely influenced by the data quality
- Research challenges
  - Application of probabilistic methods in dynamic studies

Thank you for your attention

Power system analysis

- Short term
  - Power flow analysis
  - Fault analysis
- Long term
  - Operation planning
  - System planning
- System model depends on the type of the analysis to be performed
  - Deterministic model ➔ short term analysis
  - Probabilistic model ➔ long term analysis

Deterministic analysis : Load Flow

- Basic Load flow (LF) problem formulation

Y=g(X)
Z=h(X)

Y is the input vector (real and reactive injections)
Z is the output vector (power flows)
X is the state vector (Voltage magnitudes and angles)
***G, h,* are the load flow (non-linear) functions**

- Optimised Power Flow (OPF):
  - Economic merit order dispatching of generation
  - Load flow calculation and technical constraints (voltage and thermal limits) verifications
  - Rdedispatching of the generation capacity in order to eliminate constraints violations