



Simulation of Distribution Networks with High Share of Distributed Generation


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- Requirements on Distribution Network Modelling with High Share of Distributed Generation
- Required Simulation Tools & Functions
- Application Cases

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Simulation of Distributed Generation

- **Requirements on Network Modelling**
 - Integration of distributed generation into the MV- and LV-distribution networks (aggregation)
 - Data availability, variety of sources, pre-processing requirements
 - Modeling of active and reactive power controls
- **Required Analysis Tools**
 - Steady state simulation tools for medium & long term simulations
 - Probabilistic load flow
 - Contingency analysis, reliability assessment, etc.
 - Time domain RMS/EMT simulation for short term transients

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Simulation of Distributed Generation

DIgSILENT *PowerFactory* Software, v14

- *Microsoft Windows* based integrated solution for analysis of large complex power networks
- Installations in more than 110 countries, > 10000 licenses
- Multiple interfaces for On- & Off-Line integration

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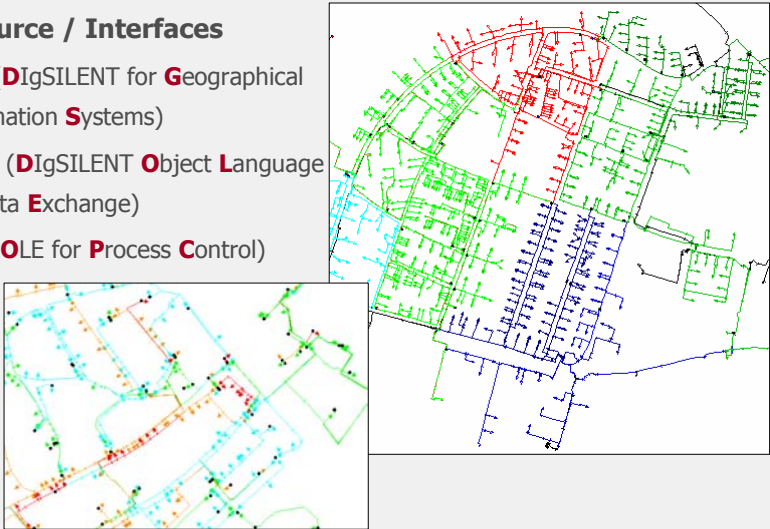
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Requirements on Network Modelling


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Modelling of Distribution Networks

- **Data Source / Interfaces**
 - **DGS** (**DIgSILENT** for **G**eographical Information **S**ystems)
 - **DOLE** (**DIgSILENT** **O**bject **L**anguage for Data **E**xchange)
 - **OPC** (**O**LE for **P**rocess **C**ontrol)

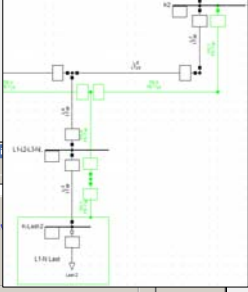
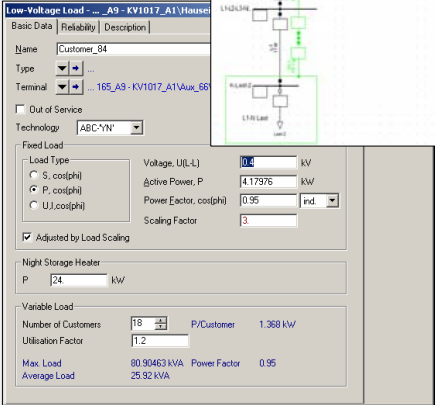


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Modelling of Distribution Networks

- **Special Characteristics:**
 - 3-phases, 4-wires model (L1-L2-L3-N, E)
 - DC & AC, balanced & unbalanced systems
 - LV-Loads with coincidence factors
 - Feeders definition and scaling
 - Distributed generation


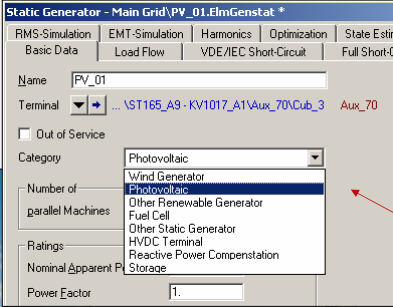
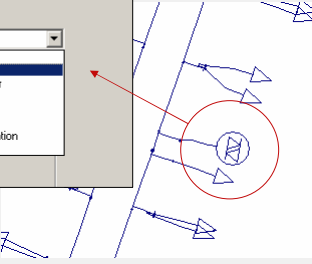




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Models of Distributed Generation

- **DC-Sources with inverter**
 - Photovoltaic
 - Storage, Batteries
 - Fuel Cells
- **PF Solution**
 - Static generator model
 - Detailed dynamic model

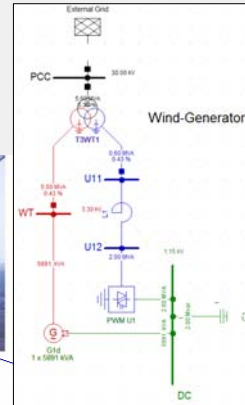


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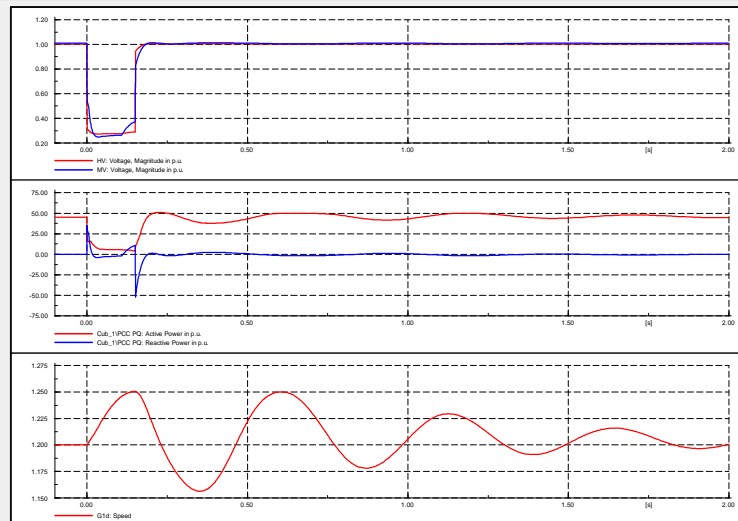


Models of Distributed Generation

- **AC-Sources with Converter** (variable speed)
 - Wind generator with fully rated converter
 - Wind generator with DFIG
 - Micro Turbines
- **AC-Sources without Converter**
 - Co-Generation
 - Induction machine wind generator
- **PF Solution**
 - Static generator model
 - Induction generator model
 - Detailed dynamic models



Dynamic Response of DFIG Wind Generator



DFIG response to a strong voltage dip



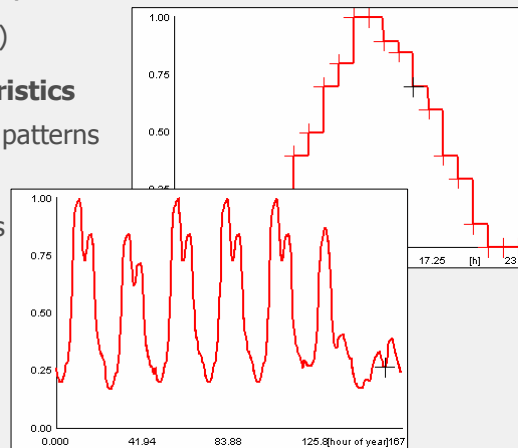
Non Dispatchable Distributed Generation

- **Non Dispatchable Distributed Generation**

- Wind generation (wind speed)
- Photovoltaic (solar radiation)

- **Time Dependent Characteristics**

- Time dependent generation patterns (daily, weekly, etc.)
- Continuous & discrete scales
- Linear, polynomial, spline, Hermite interpolation
- External measurement files
- *PowerFactory Monitor*




Dispatchable Distributed Generation

- **Dispatchable distributed generation**

- Fuel cells, micro turbines
- Co-generation, Bio-Mass

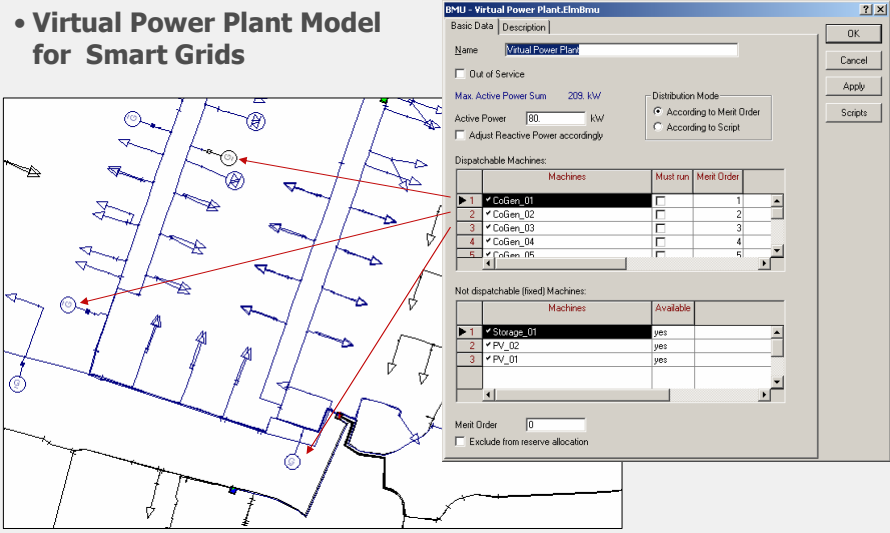
- **Wide area control algorithm / smart grids**

- Power/Frequency controller
- Virtual Power Plant Model
- Built-In security constrained optimal power flow dispatch algorithms acc. to merit order
 - Minimization of Fuel Cost
 - Minimization of Losses, etc.
- Interface User-Defined Optimization Algorithms via DPL-Scripts, C/C++ and Matlab/Simulink interfaces




Dispatchable Distributed Generation

- Virtual Power Plant Model for Smart Grids



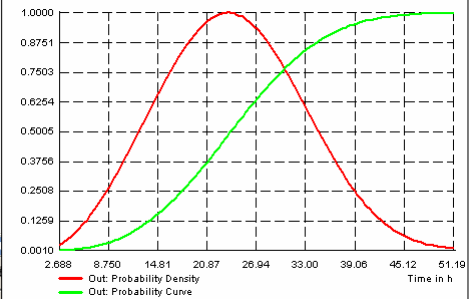
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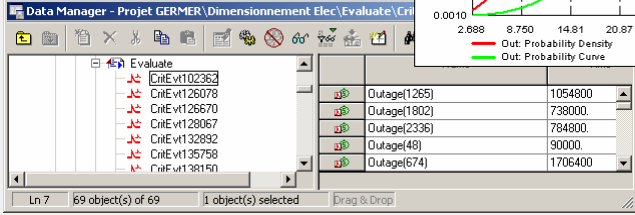


Reliability Assessment

- Stochastic Models for Failure Analysis
 - Weibull distribution for:
 - Main time to failure
 - Repair time
- Monte-Carlo Simulation
 - Evaluation of critical contingencies


State Duration Matrix:					
	States	Mean h	Variance h	Beta	Lambda h
▶ 1	In	8735	8735	1	8735
▶ 2	Out	24	8.722716	3	26.87632






Outage ID	Count
Outage(1265)	1054800
Outage(1802)	738000
Outage(2336)	784800
Outage(48)	90000
Outage(674)	1706400

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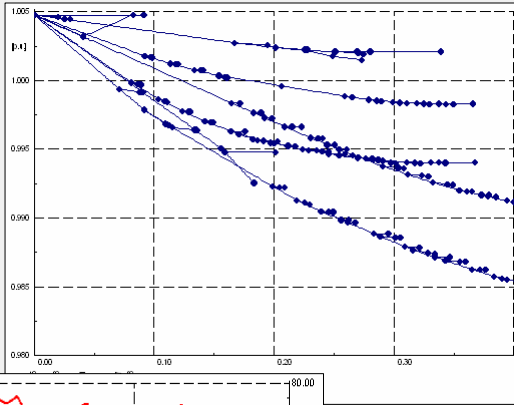
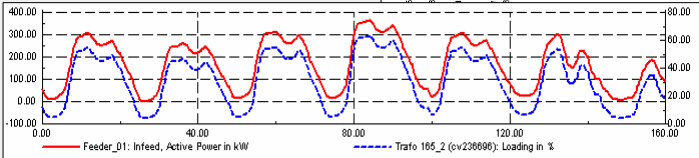


Power System Analysis Functions



Power System Analysis Functions

- Probabilistic Load Flow Calculation
- Time Sweeps
- DPL Scripting Language
- Voltage Profiles
- Reliability Assessment
- Dynamic RMS/EMT Simulations

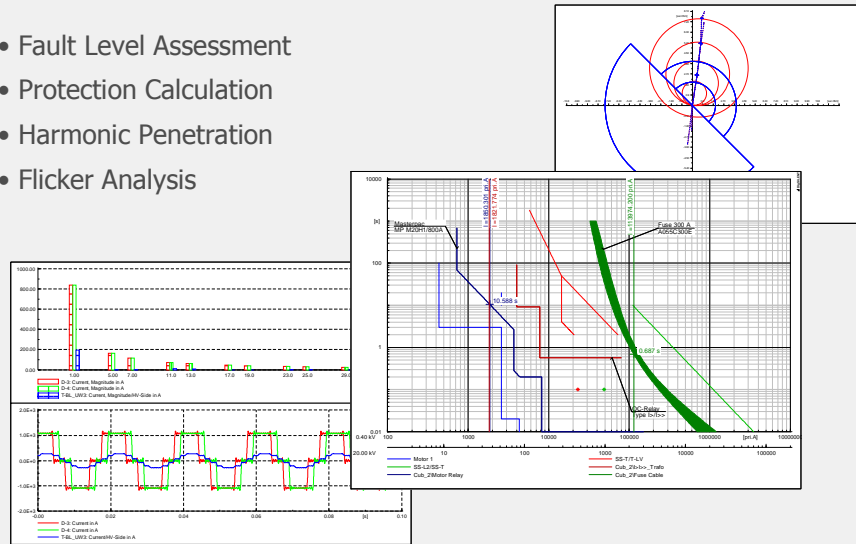





Power System Analysis Functions



- Fault Level Assessment
- Protection Calculation
- Harmonic Penetration
- Flicker Analysis



Application Cases



Application Case 1

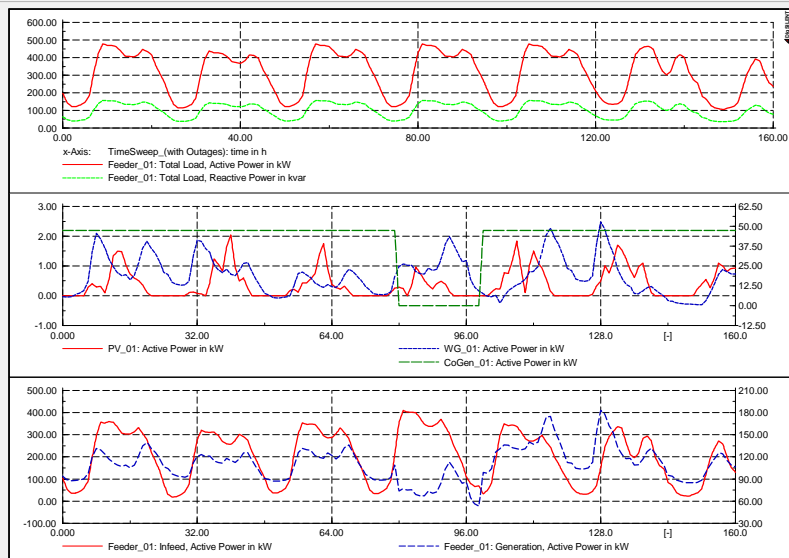




Description:

- Infeed from 20 kV network (MW balancing)
- Central dispatch of co-generation acc. to merit order (Virtual Power Plant)
- Feeder Demand:
 - Min: 100 kVA
 - Max: 500 kVA
- Distributed photovoltaic, wind and co-generation
- Transformer / SS sizing ?



Application Case 1





Application Case 2



Description

- Low-voltage distribution network in isolated operation
- Distributed generation with fuel cells, co-generation and battery
- Wide area control:
 - Centralized dispatch of co-generation
 - Power balancing by fuel cells adjustment
 - Battery reserve

Reliability Assessment of Power Supply

- Required battery size?

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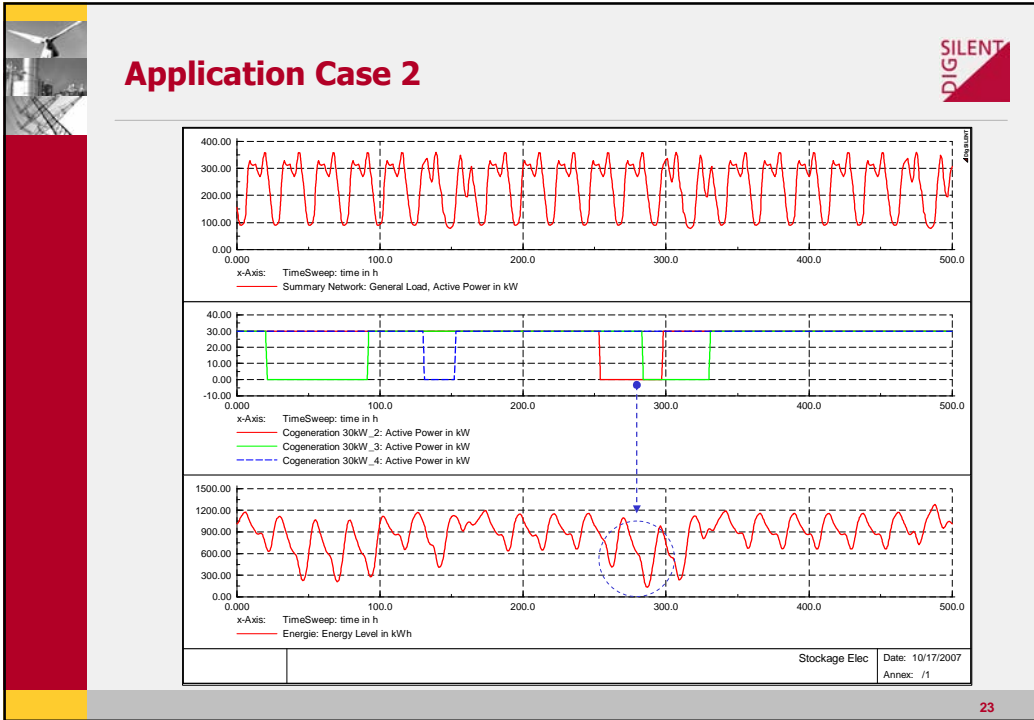


Application Case 2

Multi-Level Monte-Carlo analysis approach

- Generation adequacy
 - Demand generation balance
- Define outages based on stochastic analysis
 - Generation failure models (> 100 years)
 - Evaluation of outages over 1 million hours (> 100 years)
- Identification of critical outages based on power at risk
 - Power supply from the battery depending on power outage (co-generation)
 - Minimum energy level in the battery
- Time series simulation of critical outages

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- ## Conclusions
- Overview of models of distributed energy sources and their flexible integration into power system distribution networks in the DIGSILENT *PowerFactory* software
 - Wide-area control algorithms, including built-in DPL scripts and C/C++ or Matlab/Simulink interfaces for user-defined control algorithms
 - Integration of distributed generation requires complex power system analysis functions, including probabilistic load flow, reliability assessment, dynamic simulation among others
 - Application cases with distributed generation have been presented, including smart, wide-area control strategies and functions of the DIGSILENT *PowerFactory* software.
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Thanks for your attention ...

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