DIgSILENT PowerFactory

Integrated Power System Analysis Software

Generation * Transmission * Distribution * Industrial

Product Information

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Germany

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1. Introduction

The development of **DIgSILENT** (**DIg**ital **SI**mu**L**ator for **E**lectrical **N**e**T**work) software began in 1976, and utilized the talent of many experienced power system engineers and software developers directly involved with the planning, operation and maintenance of power systems. Since the inception of **DIgSILENT**, the program has grown to incorporate a vast array of analysis features that are required to plan, operate and maintain any aspect of the power system.

The new **DIgSILENT PowerFactory** software is an integrated power system analysis tool that combines reliable and flexible system modeling capabilities, with state-of-the-art solution algorithms and a unique database management concept. The **PowerFactory** concept was initiated in 1993 when the decision was made to re-engineer the already successful **DIgSILENT** Version 10.31 with improved solution algorithms and advanced software technology incorporating an object-oriented database. **PowerFactory** is setting new standards in functional integration, by incorporating a feature that can best be described as "**Active Documentation**". This flexible feature allows the user to create detailed power system models in a single database, allowing model functionality to be easily extended to specify a wide range of steady state, time domain, frequency domain and stochastic system characteristics, for all analysis requirements.

PowerFactory incorporates an impressive and continuously growing list of simulation functionality including:

- Load Flow and Fault Analysis of complete AC/DC network representation, and allows meshed and mixed 1-,2-, and 3-phase AC and/or DC networks to be modeled.
- Low Voltage Network Analysis
- Distribution Network Optimization
- IEC Cable Sizing
- Dynamic Simulation
- EMT Simulation
- Eigenvalue Analysis
- System Identification
- Protection Analysis:
- Harmonic Analysis
- Reliability Analysis
- Voltage Stability Analysis
- Contingency Analysis
- Power Electronic Device Modeling
- Grounding
- A/D Interfacing
- Interface for SCADA/GIS/NIS
- Compatibility with other software systems such as PSS/E & PSS/U
- Multi-User Database and User Accounting
- Advanced Tools: Optimal Power Flow and Production Planning

PowerFactory - the new generation power system analysis software was first released in 1997 providing the required product stability to guarantee efficiency in your daily application.

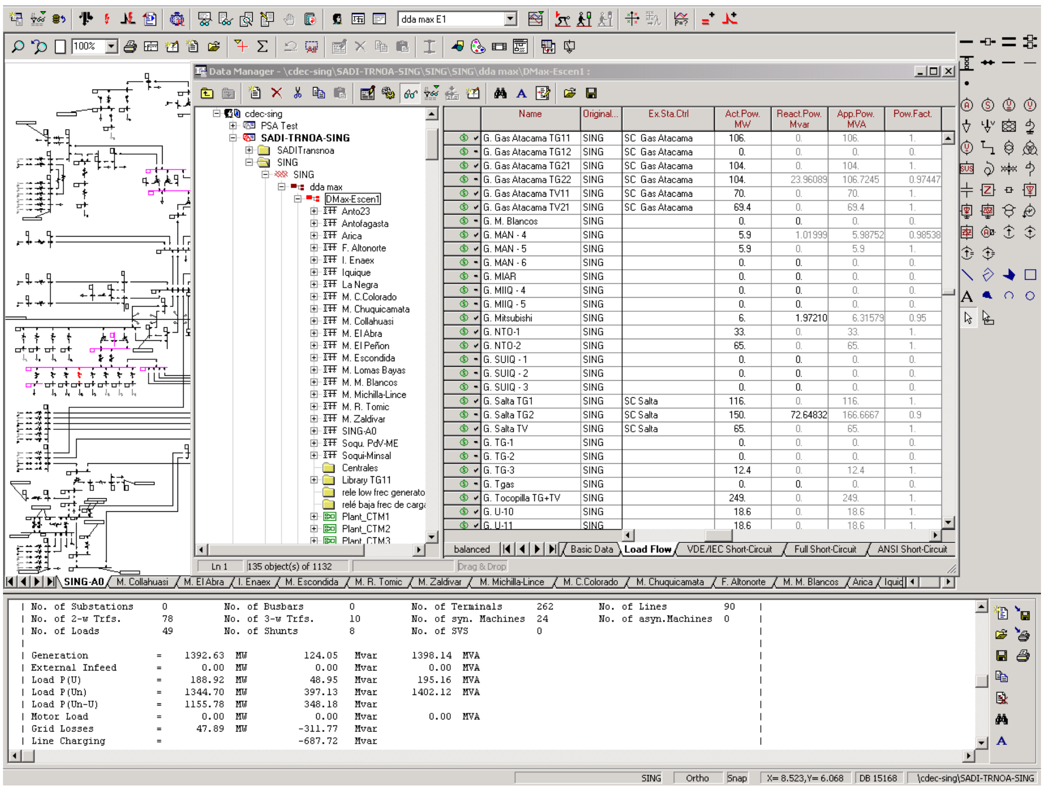
2. What Makes **PowerFactory** Unique

There are many commercial packages available that can address most power system analysis problems. However, these packages differ considerably in their integration, result validity and computational efficiency. This is due to a variety of approaches employed to incorporate the following software requirements:

- General software package design.
- Data structures and redundancy.
- Precise object definition.
- Mathematical formulation.
- Solution techniques.
- Programming and maintainability.
- Man-machine communication structures, techniques and compatibility.
- Versatility.
- Functional interaction.

DIgSILENT PowerFactory succeeds in amalgamating the requirements in each of these areas, to combine sophisticated database techniques, for the efficient organization of system data and projects, with a flexible system modeling capability and state-of-the-art solution algorithms. The combination of these features in one fully Windows 95/98/NT/2000/XP compatible package offers the user a high degree of flexibility, and a capability to analyze any aspect of the power system, both, efficiently and accurately.

DIgSILENT PowerFactory is the leading product with respect to integrated modeling capabilities and solution algorithms. It provides all required models and techniques of modern power systems.



3. General Concept

DIgSILENT PowerFactory comes with a number of advanced features introducing highest flexibility and providing best possible user support and quality assurance mechanisms.

Functional Integration

DIgSILENT PowerFactory software is implemented as a single executable program, and is fully Windows 95/98/NT/2000/XP compatible. The programming method employed allows for a fast 'walk around' the execution environment, and eliminates the need to reload modules and update or transfer results between different program applications. As an example, the power flow, fault analysis, and harmonic load flow analysis tools can be executed sequentially without resetting the program, enabling additional software modules and engines or reading external data files. Total integration is our key concept for fast and reliable development of future generations of the **PowerFactory** software.

Vertically Integrated

A special feature of the **DIgSILENT PowerFactory** software is the unique vertically integrated model concept. This allows models to be shared for all analysis functions and more importantly, for categories of analysis, such as "Generation", "Transmission", "Distribution" and "Industrial". No longer are separate software engines required to analyze separate aspects of the power system, as **DIgSILENT PowerFactory** can accommodate everything within one integrated frame and one integrated database.

Database Integration

DIgSILENT PowerFactory provides optimal organization of data and definitions required performing any type of calculation, memorization of settings or software operation options. There is no need in tedious organization of several files for defining the various analysis aspects. The **PowerFactory** database environment fully integrates all data required for defining cases, scenarios, single-line graphics, outputs, run conditions, calculation options, graphics, user-defined models, etc. There is no need any more to keep and organize hundreds of files on hard disc.

- **Single Database Concepts**: all data for standard and advanced functions are organized in a single, integrated database. This is applied also for graphics, system stages, study case definitions, outputs, run conditions, calculation options, fault sequences, monitoring messages as well as user-defined models.

- **Multi-User Operation:** support of multi-user database server operation with the definition of accesses rights, user accounting and data sharing.

System Stage Management: in **DIgSILENT PowerFactory**, project and study case development is a unique application of the object-oriented software principle. Standard software packages often require the user to create a large number of similar saved cases, with multiple nested directories for large complex networks and studies. However, **DIgSILENT PowerFactory** has taken a totally new approach, and introduced a structure that is both easy to use while avoiding redundancy for System Stages and Study Cases.

4. Modes of Operation

Windowing Operation

DIgSILENT PowerFactory performs within a fully graphical windowing environment, allowing the application of the most modern and intuitive man-machine communication techniques. It follows the latest Windows standards, including tree-list boxes, integrated browsers, tab-pagers, tab-bars, and docking windows, etc. In order to be independent of specific manufacturers, proprietary libraries such as MFC are not used.

Separate windows are available for output display, single line graphics and substation drawings, data base editing and calculation functions. Additionally, multiple windows in each window class may be open simultaneously to show for example different aspects of the same substation graphic, or to highlight different hierarchies in a network single line graphic.

Full Interactive Mode

The most basic (but nevertheless quite powerful) **DIgSILENT PowerFactory** mode of operation can be found in the interactive command line. All activities executed by the user are entered automatically in a special command Activity Window. This window can be viewed at any stage, and be used for entering command sequences. The interactive mode can be combined with the DIgSILENT Script Language DPL providing a powerful tool for implementing user-defined procedures and batch mode operation.

Engine Mode

DIgSILENT PowerFactory may be operated as a background process in situations where it is integrated into GIS/NIS or SCADA systems or linked with other simulation tools such as SIMULINK, ASPENTECH's process simulation tool or other software systems requiring interaction with network analysis procedures. The engine mode also features parallel processing with other **PowerFactory** processes. The "Engine Mode" capability permits the remote control of all **PowerFactory** functions.

5. Data Management

DIgSILENT PowerFactory comes with a new and innovative philosophy of storing system data, system stage definitions, case data and runtime parameter. Instead of requesting the user to edit, organize and maintain hundreds of files thereby keeping most information fully redundant, **PowerFactory** features a powerful data manager that serves as a window to the built-in relational database.

Introducing Intelligent Data Structures

In order to minimize data redundancy, object data is split into Type and Element Data so that the same set of data can be used many times via type references. For most network objects such as cables, motors or relays, comprehensive libraries are provided allowing user access and maintenance on various levels.

Characteristics defined as vectors or matrices can be applied to perform parametric studies with discrete or continues scales. The application of characteristics allows keeping a perfect overview on data that change from case to case, such as loads, generation, set points or transformer tap position, without having the need to create and organize additional and separate cases.

System Stages and Study Cases are defined on the basis of easy-to-use mechanisms for incremental information handling which creates and maintains base cases, alternatives, expansion stages and operational scenarios. The maintenance of these variants will automatically update or delete extensions of subsequent stages. In addition, full support is given to the comparison of appropriate variants or alternatives.

The generation and editing of cases is not done by an additional 'Job-File Editor' but, instead, is included in the program itself, utilizing modern windowing techniques for all data entry and maintenance. Consequently, any modification of system data and structures is done within the program's memory and on the database level at the same time. This technique allows the fastest possible program handling, since typical calculation sessions do not require the time consuming and tedious standard procedures like "editing - file saving", " program restart - update of data, etc".

Libraries

The user is free to define and organize his own integrated libraries for all kind of data, grids, output definitions, forms, user-written models, frames, fault sequences, DPL scripts, etc. Special importance is given for equipment types such as transformers, cables, generators, motors, conductors, tower configurations, controllers, relays or any other object support by the PowerFactory software.

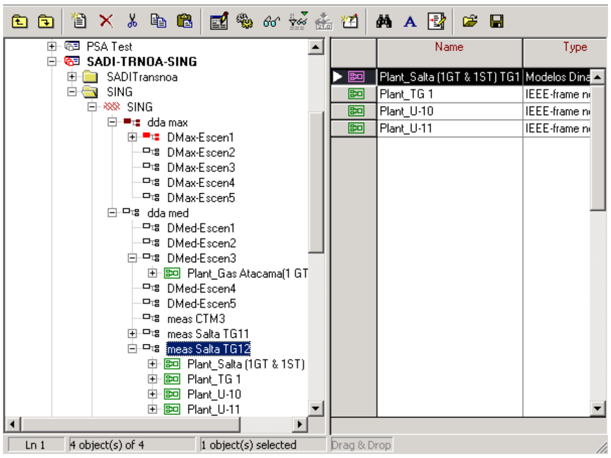
PowerFactory is supporting Global Libraries and User Libraries with respective access and modification rights. Libraries can be imported and exported to many other software systems such as MS-EXCEL.

System Stage Management

In general, any network structure is organized around Grid Definitions such as the transmission systems, the distribution networks, industrial complexes, composite models or neighboring systems. Here, the user is free to organize all data according to his individual requirements.

Configuration changes within each Grid Definition are defined as System Stages – sometimes also called "Variants". They are represented in a tree structure when there are hierarchies and dependencies. Within each project, any number of System Stages may be created to represent any number of study alternatives to the base case networks. All data - equipment data, structural data and graphical information - is added or subtracted via the “incremental objects” of System Stages. This, fully non-redundant organization principle provides basic quality assurance mechanisms which are required to keep base cases and any subsequent alternatives consistent.

To further reduce data redundancy within **DIgSILENT PowerFactory**, object data is split into type and element data. This means for example, that a section of “cable” from say node A to node B in a network, requires a certain data type (e.g. NACBA), and element data specific to that section, e.g. length, reduction factor, etc. This database strategy has the advantage that any updated type information will be automatically incorporated into all System Stages employing that type.

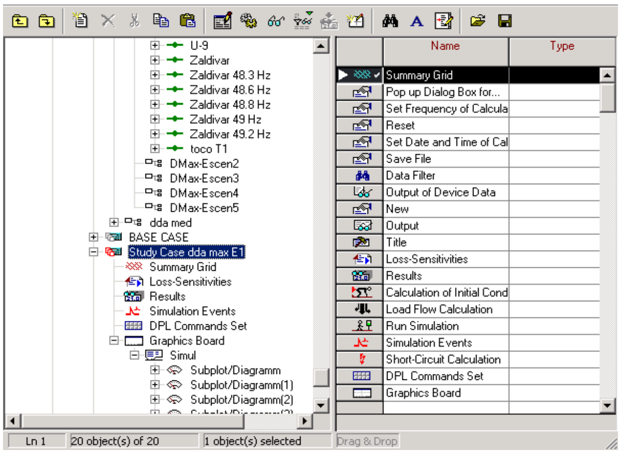


Study Case Management

Study Cases are used to define and activate certain functions and parametric alternatives of System Stages. They allow to define which grid variants, network interconnection options or system expansion stages are activated. Additionally, they are used to initialize certain sets of calculation commands such as:

- Command options
- Trigger settings
- Simulation events
- Graphical desktop definitions
- Display options
- System Stages

The Study Cases also save all data necessary for reproducing previously obtained results on basis of a single mouse-click.



Basic Quality Assurance Principle - No Data Redundancy

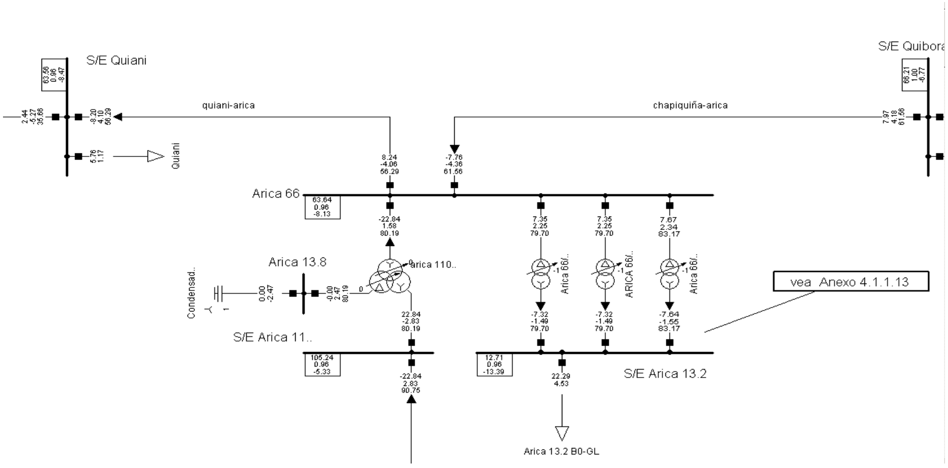
One benefit of this data structure is that large power companies have only a single database with a single set of data to manage. In case of a change in network data, updating the database only requires the database administrator to make one change and all System Stages of all applications of all network simulations are updated automatically. This feature improves quality assurance and is an attractive feature to many power companies.

6. The Graphical Editor

Interactive Graphics

DIgSILENT *PowerFactory* also provides a fully integrated graphical editing environment, which enables the user to:

- Draw and modify electrical grids for integrated network and area diagrams, classic single line and substation configuration diagrams, with a configurable multi-layer network viewing and plotting capability;
- **Multi-Layer-Techniques**: view and operate several windows with different layers and grid sections simultaneously. Utilize several graphical representations of the same system at the same time;
- **Auxiliary graphics** are best used to further document your drawings via text boxes or sketches;
- Utilize a comprehensive “drag and drop” power system element library containing transformers, generators, HVDC systems, etc., which the user is free to expand to include new elements for both devices and types;



- Define substation diagrams that generate the graphical representation of basic HV and MV substation types automatically according to the ABB handbook, namely for:

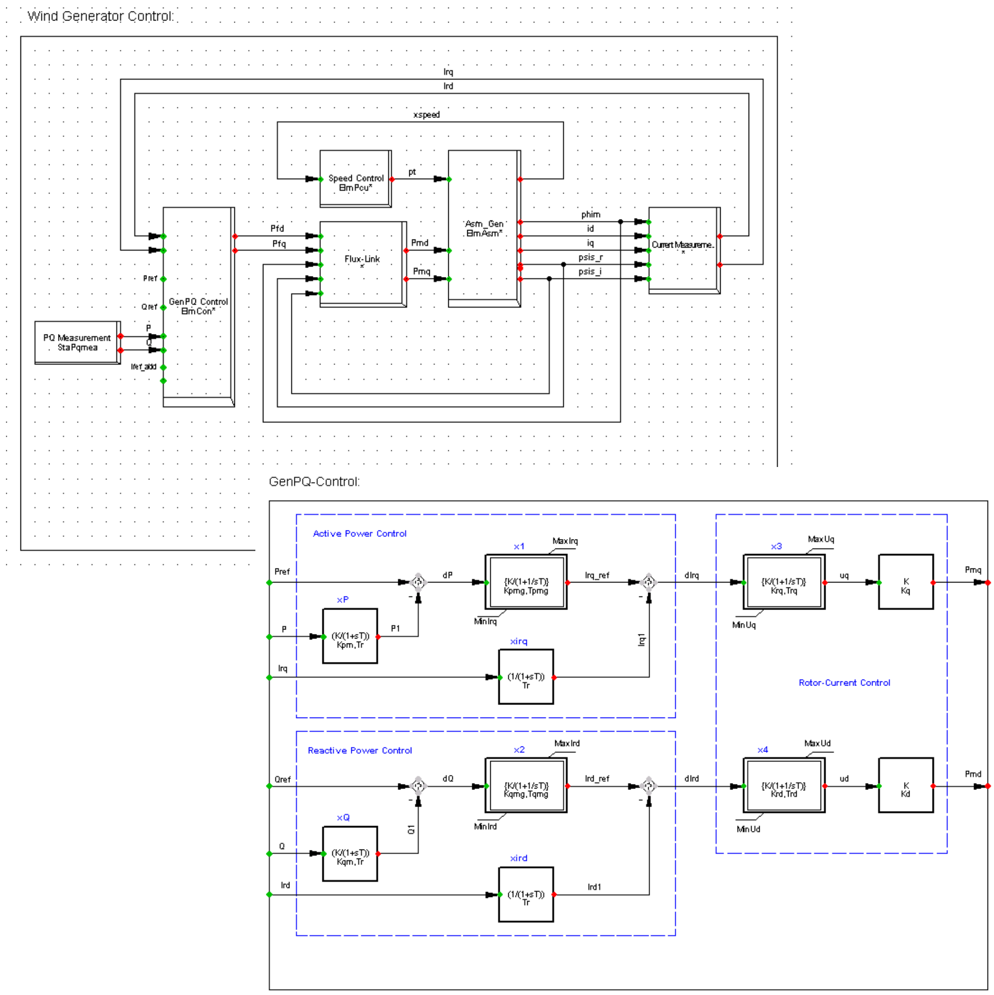
    - 1-, 2- and 3-busbar systems with and without transfer buses
    - U-Bars
    - Ring main schemes
    - 1 1/2 breaker schemes

- Automatically modify library-generated substations according to user specific requirements;
- Reflect any editing activity on the graphical level immediately in the case definition;
- **Network Coloring**: define different colors and line widths to represent voltage levels, voltage bands, areas, grids, isolated voltage levels, or other user-defined criteria;
- Define single or multiple breaker and disconnectors in cubicles and hence in the station graphic;
- Update, adjust and compare single line diagrams and case definitions to guarantee that graphical versions of grids are consistent;
- Initiate calculation events directly within the graphical environment, including circuit breaker switching, fault implementation and other data changes;
- **Results Display:** Display calculation results immediately in result boxes within the single line diagram. All program variables and signals can be displayed according to the most flexible user definition for various object categories and levels;
- Access equipment editing menus in the single line diagram by cursor selecting the appropriate element, region or composite model;

- Zoom-in or zoom-out of area networks or composite model graphics;
- Show a mixed representation of detailed substation and single line graphics;
- Display any calculation result, object parameter or additional user text at any location according to user definable settings;
- Elements in object browsers can automatically be searched and marked in graphics for visual identification

Block Diagrams for User Written Models

DIgSILENT PowerFactory features the most user-friendly, flexible and powerful definition of user written models within a fully graphical environment. The integrated graphical editor provides the needed flexibility to implement the most complex models also supporting unlimited model nested. Connectivity checks are permanently active ensuring proper "wiring" of all frame signals and model connections.



7. Documentation

DIgSILENT PowerFactory provides various methods and options to document input and output data, report and print calculation results and to generate graphical documents.

Text Output

Following the classical approach, text pages can be generated to report on entered equipment data, summarize calculations results, print detailed reports on load flows and short circuit results, document harmonic analysis results, provide lists on relay characteristics and relay settings, or summarize on DSL models. All reports can be printed in graphical format on standard printers in various formats.

Text output is based on forms with flexible definitions according to user needs. At any time, user may change reporting language, layout and variables. Standard outputs are pre-defined in A5 size format.

There are a number of different methods to select objects for which an output shall be generated. Based on a pre-defined or user-definable "Selection" various filters may be stored and applied accordingly. Filter definition is provided via Data Manager Selection, Object Manager Selection or directly on the level of the single line graphics.

Spread - sheet Output

Both, Data Manager as well as the Object Manager feature a direct link with the Windows Clipboard allowing to directly transfer any variable into other application programs. As special *Flexible Page* definition is supported which makes it possible to report and display any variable such as input parameter, calculation result, DSL signal or DPL script variable.

Virtual Instruments

DIgSILENT PowerFactory applies the concept of Virtual Instruments (VI) as a tool for displaying any calculated result or variable. These results may be in the form of bar graphs, plotted curves, or even tables of values, with all display representations completely user-definable. VIs are used to display protection curves, harmonics analysis results or to view electrical variables from any location in the network single line diagram, and any model variable during RMS and EMT simulations. Many VIs provide additional build-in functionality such curve labeling and measuring, scaling, curve fitting, filtering and digitizer functions.

Graphical Documentation

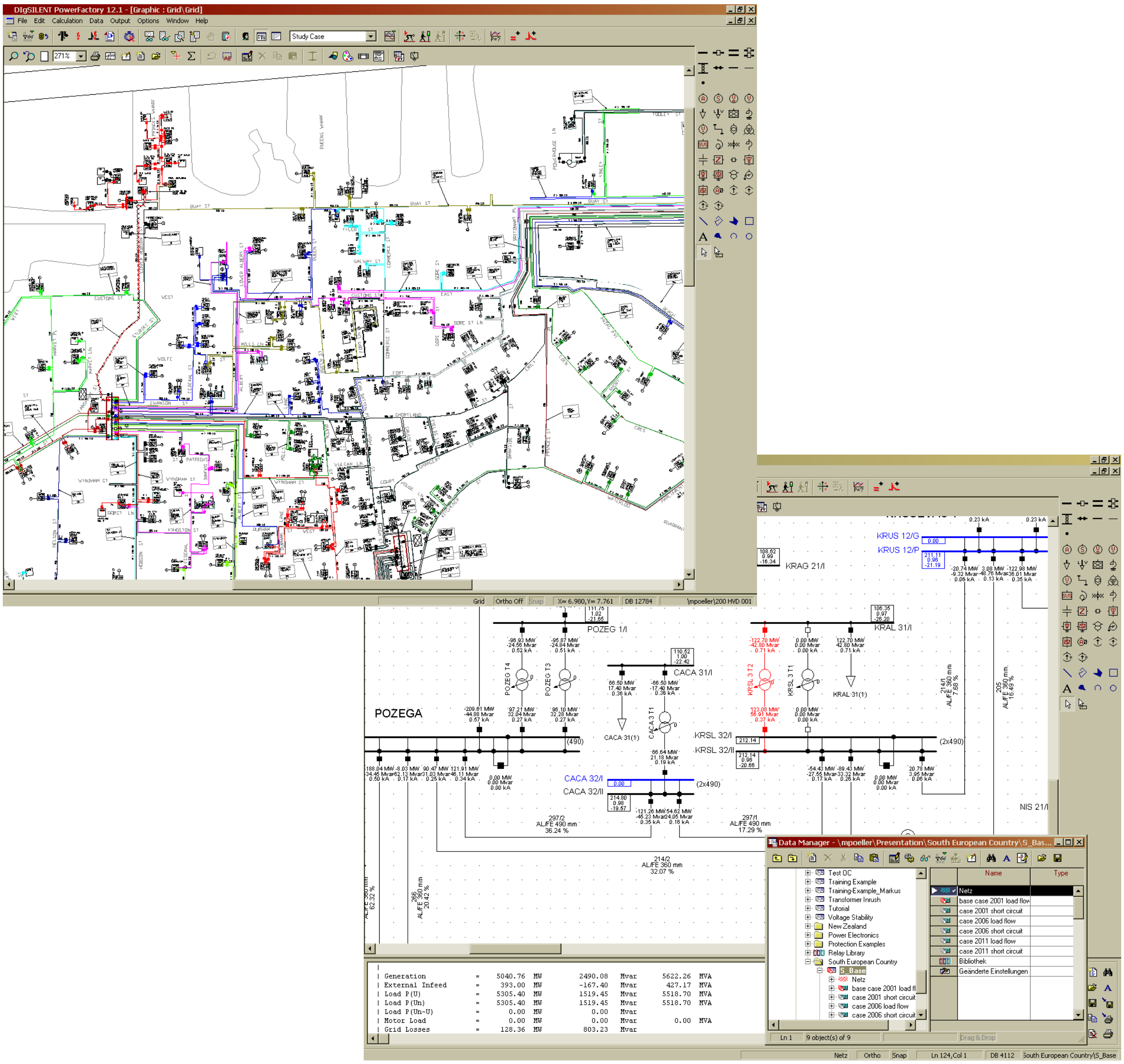
In general, any printing or plotting device supported by the Windows Print Manager can be used to produce high quality graphical documents from within the program. Graphical interchange with other software systems via the Windows Meta File (WMF) and Bit Map exchange is available with high precision coordinates. In addition, format conversion from WMF to other formats like DXF is available via internal program format conversion routines.

8. Load Flow Analysis

Within the Load Flow analysis environment, the accurate representation of a variety of network configurations and power system components is possible. Any combination of meshed 1-, 2-, and 3-phase AC and/or DC systems can be represented and solved simultaneously, from HV transmission systems, down to residential and industrial loads at the LV voltage levels. The Load Flow tool accurately represents unbalanced loads, generation, grids with variable neutral potentials, HVDC systems, DC loads, adjustable speed drives, SVS, and FACTS devices, etc., for all AC and DC voltage levels.

DIgSILENT PowerFactory also incorporates an enhanced non-decoupled Newton-Raphson solution technique, with current or power mismatch iteration, and typical round-off errors below 1 kVA for all buses. The superior stability and convergence of the implemented algorithms is making other traditional load flow methods such as Current Iteration obsolete. Several iteration levels are guaranteeing convergence under all conditions. If for example the Load Flow is tending towards divergence, due to unrealistic constraints, the solution algorithm will analyze the constraints and modify them automatically.

DIgSILENT PowerFactory is introducing a new, intuitive and easy-to-use modeling technique fully avoiding the definition of bus types such as SL, PV, PQ, PI, AS or any other definition often required to model special devices. PowerFactory simply provides such control mechanisms and devices characteristics which are found in reality.



More Load Flow Analysis Features

- Supports device characteristics, such as loads with voltage dependency and asynchronous machines with saturation and slip dependency, etc.
- Practical station control features with various local and remote control modes for voltage regulation and reactive power generation. Reactive power is automatically adjusted to ensure that generator output remains within its capability chart.
- Comprehensive area/network power exchange control features using Secondary COntrollers (SCO) with flexible participation factors.
- Transformer OLTC able to control local or remote bus voltages, reactive power flows as well as voltage-drop compensation (LDC) within distribution systems.
- Devices controllers for shunts, double-fed asynchronous machines and other power electronics elements such as PWM converters, inverters, rectifiers or integrated FACTS devices.
- Local and remote control mechanism for SVS systems. Automatic and continuous control of the TCR and TSC switching is performed within component ratings to hold voltage at a given value.
- Correct representation of transformer vector groups and phase displacement.
- Shunts can be modeled to consist of a combination of series and/or parallel connected capacitors, reactors and resistors. Shunts can be connected to busbars and feeders or to the remote end of cables and lines. Filters may consist of any number of shunt combinations. Automatic shunts switching can be included in the automatic voltage regulation.
- Full support of any parameter characteristic and scale to allow parametric studies or easy definition of loading scenarios or load profiles.

Contingency Analysis

The new **DIgSILENT PowerFactory** Contingency Analysis functions have been designed to offer a high degree of flexibility. There are now three different ways that contingency analyses can be carried out:

- By analyzing a single contingency. This is achieved by selecting one or more objects for simultaneous outage, and running a load flow case to analyze the outage.
- By creating one or more contingencies, each of which may define one or more objects to be taken out of service simultaneously. Load flows are then run to analyze all outage combinations.
- By running a DPL script that specifies certain contingencies, which are then analyzed sequentially.

A detailed report of each contingency case for each option is available after the analysis has been completed.

Further Special Functions

- Analysis of system control conditions
- Calculation of dV/dQ sensitivities.
- Parameter scaling for the determination of voltage stability curves (V-P) and transfer limits (Voltage Stability Analysis)
- Determination of "Power at Risk"
- Automatic Outage Simulation (n-1), including detailed reports for user-defined voltage limits and equipment overloading
- Support of DPL scripts e.g. to perform load balancing, determination of penalty factors or any other parameter required.

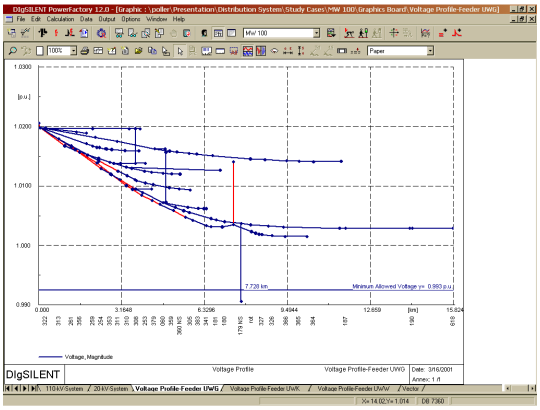
Load Flow Results

- Display of any variable within the single line and station diagram according to a most flexible VI definitions;
- Fully flexible filter mechanisms to display objects in colored mode;
- Detailed analysis reporting, which can list overloaded system elements, unacceptable bus-voltages, islanded system areas, out of service components, voltage-levels, area summaries, and many other documentation features;
- Detailed text output with pre-defined or user-defined filters and levels;
- Support of the *Flexible Page* with free variable definition and DPL interactivity;
- Result export to other software system such as MS-EXCEL

Radial Feeder Analysis

DIgSILENT *PowerFactory* provides a number of special functions that make LV analysis more transparent and adopted to practical constraints.

Feeder Plots



Using the most innovative "Feeder plot" a special, high level graphical display feature (Virtual Instrument, VI) is provided to increase transparency in grid loading and voltage profile analysis across several voltage levels. Full interactivity is given to access via the VI all relevant data and structures.

Feeder Load Scaling

Feeder load scaling is a feature that allows to automatically adjust the individual bus loads to match a given total feeder load. An option is available to decide which loads of a feeder will participate in the scaling procedure.

9. Optimal Power Flow

The **DIgSILENT PowerFactory** Optimal Power Flow (OPF) serves as the ideal complement to the existing load flow functions. Whereas the standard load flow calculates branch flows and bus bar voltages based on specified "set points" (active/reactive power generation, generator voltage, transformer tap positions, etc.) the OPF also calculates the "best possible" values for "higher level set points" considering a user specified objective function and a number of constraints. In this way, the OPF adds intelligence and consequently improves efficiency and throughput of power system studies significantly. The OPF avoids the tedious and manual search for a "best possible solution" via several, iterative runs requiring a number of manual modifications, which quite often are leading to un-comparable solutions when performing various load flow sequences to arrive at certain conditions as defined by various load flow scenarios. From practically any starting point, within a couple of fast iterations, the OPF will assure a globally optimal and reproducible solution, satisfying the defined system limits while minimizing the applied cost functions.

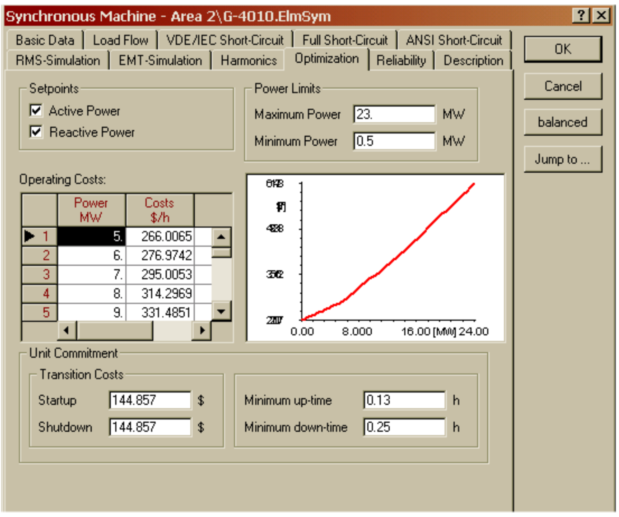
From point of view of software application, the OPF is just an enhanced function of the standard load flow, being fully integrated, powerful and easy-to-use. The OPF is simply accessed via an extra page of the load flow option definitions.

The OPF supports a number of new applications typically found in today's less-regulated power markets such as:

- Scheduling of Ancillary Services for reactive power and active power
- Development of system reference scenarios
- Transfer capability analysis
- Determination of voltage stability limits
- Implicit Penalty Function consideration
- Comparative reliability analysis studies

Supported **Objective Functions**:

- Minimize system losses
- Minimize fuel costs (*based on non-linear fuel cost functions for each generator)*
- Maximize profit (*considering fuel costs and load tariffs)*
- Minimize area exchange flows.



Above listed objective functions are solved under the consideration of a number of possible **constraints** to which the final solution must comply with are:

- Branch flow limits (loading)
- Bus bar voltage limits
- Generator reactive power and stator current limits
- Generator active power and reserve limits
- Transformer tap changer limits
- Adjustable shunt limits

Because the OPF can also dispatch the active power of generators considering reserve limits and the fuel cost minimization which is based on non-linear fuel cost functions, the *PowerFactory* OPF is at the same time very advanced *Economic Dispatch* function.

10. Fault Analysis

DIgSILENT PowerFactory features three-phase network fault calculation functionality based on international standards as well as the most accurate **DIgSILENT** General Fault Analysis (GFA) method.

In general the following features and options are supported for all implemented fault analysis methods:

- Includes calculation of all three symmetrical components as well as phase quantities.
- User definable fault impedance
- Calculation of short circuit quantities at a specific, selected busbar or along a defined section of line/cable, including all branch contributions and busbar voltages.
- Provision of specially designed graphs and diagrams including all quantities typically required by the protection engineer.
- Thermal overloads highlighted on the single line graphic for busbars and cables, with all equipment overloads available in a summary text report.
- A complete power flow output, including branch currents and busbar fault voltages, can be displayed for all branches and nodes, or selected busbar subsets.
- Calculation of Thevenin impedances as seen from the faulty node.
- Calculation of apparent phase impedances (magnitude and angle) at any location along a transmission line/cable or busbar, for all branches, selected subsets, or 1,2 or 3 nodes from the faulted node.

IEC 909 and VDE 102/103 Fault Calculation

For the world-wide most frequently used standard for component design, ***PowerFactory*** provides a strict and complete implementation of the IEC 909 and VDE 102/103 fault calculation standard according to the latest published versions.

- Calculation of the initial symmetrical peak current Ik" and short circuit power Sk", peak short circuit current Ip, symmetrical short-circuit breaking current Ib, and thermal equivalent current Ith (IEC 60909-0 2001). Both minimum and maximum short circuit currents can also be calculated based on network voltage c-factors.
- Support of all fault types (balanced and unbalanced)
- Automatic grid type identification
- Calculation of Ik with selectable "Decaying Aperiodic Component"
- Selectable method for calculating the Peak-Short Circuit Current in meshed networks
- User definable fault impedance, conductor temperature and c-voltage factor.
- Fault calculation can include or exclude motor contribution to the fault current.
- Provision of specially designed graphs and diagrams required by the protection engineer for protection coordination and design.

IEEE 141/ANSI e 37.5 Fault Calculation

PowerFactory provides a strict and complete implementation of the IEEE 141/ANSI e37.5 fault calculation standard according to the latest published version. Special features are:

- Transformer tap positions can be included in the fault current calculation.
- User defined fault impedance and pre-fault voltage can be included in the fault current calculation.

DIgSILENT General Fault Analysis (GFA)

Especially for protection coordination purposes or for analyzing observed system contingencies, the **DIgSILENT *PowerFactory*** General Fault Analysis (GFA) is providing the required algorithms and precision for determining the "real" short circuit currents without considering the typical simplifications or assumptions typically applied for norm based fault analysis. The General Fault Analysis (GFA) is based on an unconstrained sub-transient power flow, and takes into account all specified network devices with their full representation and pre-faulted load conditions. The general fault analysis tool is based on a complete 3-phase system representation (a-b-c phase coordinates). The analysis of multiple fault conditions is one of the most important features of the GFA.

Additional features are summarized below:

- Calculation of any asymmetrical, single or multiple fault conditions with or without fault impedance, including single and double phase line interruptions.
- The initial response of many other "event" like motor starting, generator tripping, shunt switching, load shedding, etc., may be analyzed (stability module required).

Fault Analysis Results

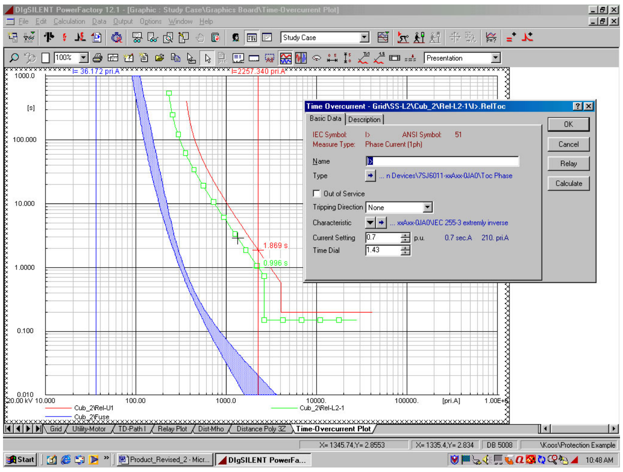
- Various reports may be produced, including detailed reporting on all short circuit levels for all faults, or alternatively, a specific report for one fault type. Special protection reports can also be generated to include impedance, current and voltage information.
- Display of any variable within the single line and station diagram according to a most flexible VI definitions.
- Fully flexible filter mechanisms to display objects in colored mode
- Detailed analysis reporting, which can list overloaded system elements, unacceptable fault currents, islanded system areas, out of service components, voltage-levels, area summaries, and many other documentation features.
- Detailed text output with pre-defined or user-defined filters and levels.
- Support of the *Flexible Page* with free variable definition and DPL interactivity.
- Result export to other software system such as MS-EXCEL

11. Protection Functions

The **DIgSILENT *PowerFactory*** protection analysis tool is an extension of the basic functional model library, containing additional devices like CTs, VTs, relays, fuses and more complex protection schemes including user-defined modeling capabilities. Additionally, there are specially designed interactive VIs (Virtual Instruments) for displaying system quantities and more importantly for modifying protection settings in the graphical environment. This last feature is especially useful, as coordinated settings between different protection schemes can be modified via the cursor in the graphical environment, which then updates the settings both in the database and simulation environment.

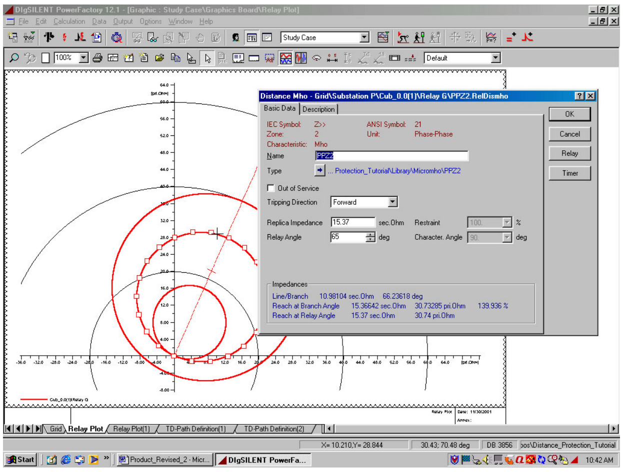
All protective devices are also fully functional under steady state as well as transient conditions, allowing device response assessment under all possible simulation modes, including load flow, fault analysis, RMS and EMT.

Protection Model Library and Functionality



The **DIgSILENT PowerFactory** protection analysis tool contains a comprehensive protective device model library and includes:

- Time overcurrent relays for 1 phase, 3 phase, ground and negative sequence time over-currents. Additionally, the relay characteristics can incorporate the following standards and solution methods:
    - IEC 255-3
    - ANSI/IEEE
    - ANSI/IEEE squared
    - ABB/Westinghouse CO (Mdar)
    - Linear approximation
    - Hermite-spline approximation
    - Analytical expressions vi build-in formula editor and analyzer
- Instantaneous overcurrent relays for 1 phase, 3 phase, ground and negative sequence time over-currents.
- Directional relays for overcurrent, power, ground current, and any combination of time and instantaneous overcurrent relays. Additionally, voltage and current polarization is used for the detection of negative and zero sequence components.



- Distance relays for phase, ground, and zone distance protection. Provision is available for incorporating overcurrent and under-impedance starting.
- Different characteristics for distance relays steps including:
    - MHO
    - Polygonal
    - Tomatoes
    - Lens
    - Circle
    - R/X Blinder
    - Offset characteristic

- Voltage relays for undervoltage, instantaneous voltage, voltage balance and unbalance.
- Additional devices include Breaker fail, Motor protection, Generator, and Out-of-step relays.
- Apart from the standard circuit breakers the model library contains Low voltage circuit breakers and Fuses

Additional to these protection functions and relays **DIgSILENT *PowerFactory*** provides further devices and characteristics for more detailed protection system modeling, such as:

- Current and Voltage transformers that include saturation effects
- Conductor, cable damage curves, cable overload curves and inrush peak current modeling
- Transformer damage curves (ANSI/IEEE Standard C57.109 – 1985) and inrush peak current modeling
- Motor starting curves, cold and hot stall, in-rush peak current modeling, and any user defined curves

All protection device models are implemented within the composite model frame environment. This allows the user to easily design and implement their own models, by utilizing the graphical user interface for constructing block diagrams (see also stability section).

Protection Co-ordination

The co-ordination of overcurrent-time protection is done graphically on basis of the current-time diagram. Relays settings are modified using Drag & Drop for moving the characteristics. Short-circuit currents, calculated with the short circuit command, are shown in the diagram as a vertical line. In addition the corresponding tripping times of the relays are displayed. Co-ordination between relays at different voltage level is also available. Therefore currents are automatically based on the leading voltage level, which can be selected by the user.

For distance protection co-ordination two powerful graphical features are integrated. The R-X diagram for displaying the tripping area of distance relays and the line impedances. Several relays can be visualized in the same R-X diagram. This might be useful for comparison of two relays that are located at both ends of the same line. The relay characteristics with the connecting line will be shown in the same R-X diagram. After short-circuit calculations the measured impedances are visualized with a marker in the shape of a small arrow or cross. From the location of the marker the user can see the tripped zone and its time of the relay. For dynamic simulation, measured impedances of the relays can be displayed online. Therefore it's possible to detect problems graphically like a power swing.

The time-distance diagram is used for checking the selectivity between relays along a co-ordination path. The relays of a co-ordination path can be displayed in diagrams for forward, reverse or for both directions. Consequently, it is very easy to check the selectivity of the relays along a co-ordination path. Two different methods for calculation of the tripping curves are provided. These are the kilometric and the short circuit method.

Kilometric method: the reach of the zones is calculated by cutting the given positive sequence impedance of the lines with the impedance characteristic of the relays.

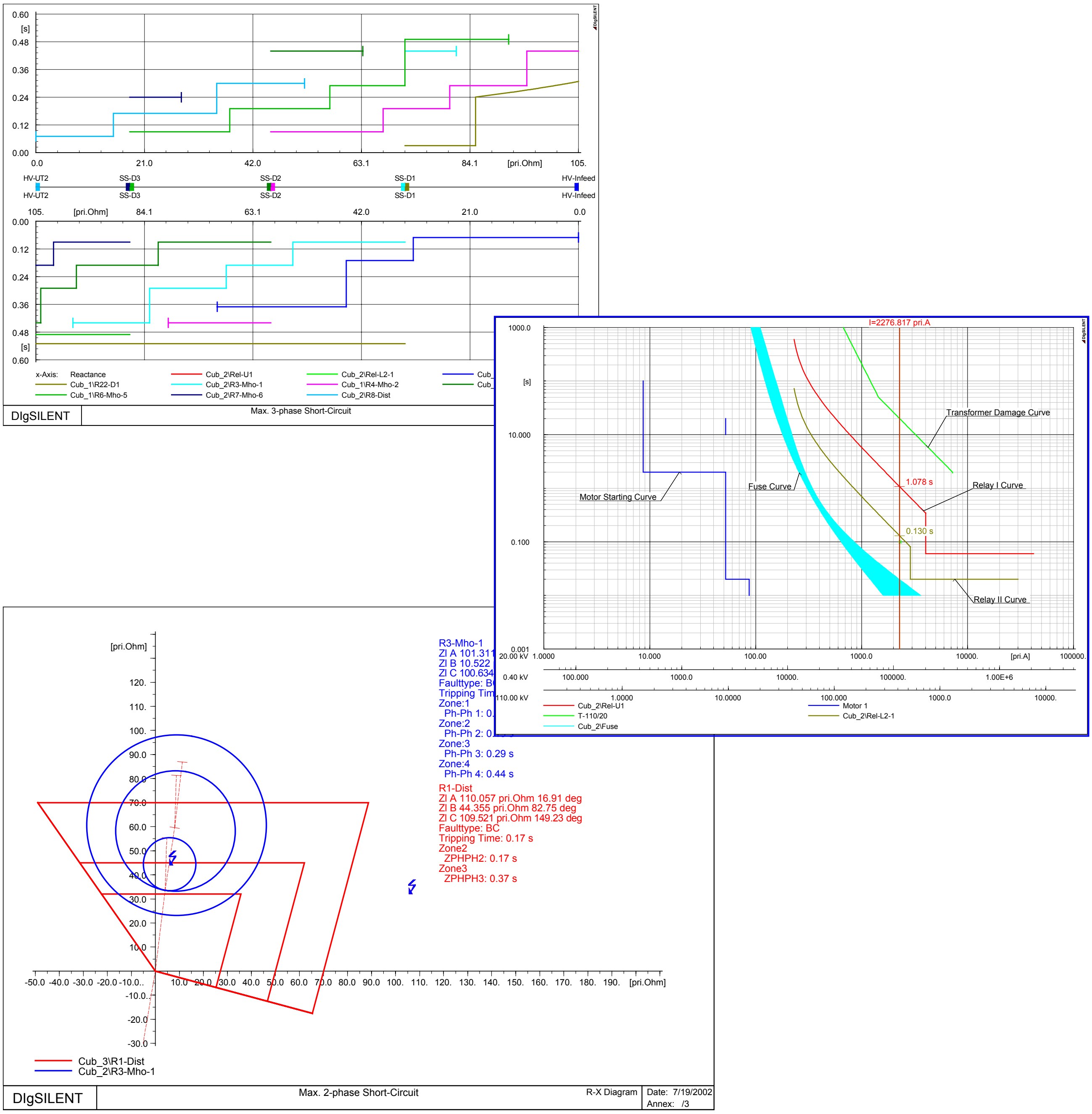
Short circuit method: this is the main method for checking the selectivity. Along the co-ordination path short-circuits (user-defined fault type) are calculated. The tripping times for the time-distance curve are determined using the calculated impedances. The starting signal of a relay is considered, too.

As special feature blocking signals or POTT (Permissive over-reach transfer tripping) PUTT (Permissive under-reach transfer tripping) are also taken into account. In addition to tripping curves of distance relays the curves of overcurrent relays can be displayed and co-ordinated in the same diagram using the short circuit method.

Both, the kilometric and the short circuit method consider breaker opening times in the calculation of tripping times. As an option the breaker opening time can be ignored.

Protection diagrams

Relay settings are modified very easily be clicking twice on the characteristics/curves. The settings dialog for the clicked zone pops up and the parameters can be modified. After confirmation of the changes with the OK button the dialog is closed and the characteristics/curves are adapted to the new settings immediately. The most important settings and commands in protection diagrams can be accessed easily using the context-sensitivity menu.



12. Harmonics

The harmonic analysis functionality is ideal for applications in Transmission, Distribution and Industrial networks for filter design, ripple control signal simulation or for the determination of network natural resonance frequencies.

For analyzing the impact of harmonics in power systems, **DIgSILENT PowerFactory** provides two basic harmonic analysis functions.

Harmonic Load Flow

The **DIgSILENT PowerFactory** harmonic load flow features the calculation of harmonic voltage and current distributions based on defined harmonic sources and grid characteristics. It allows the modeling of any user-defined harmonic voltage or current source, both in magnitude and phase including inter-harmonics. The harmonic sources can be located at any busbar in the power system and may be implemented within any network topology. Most power electronic devices carry their harmonic characteristics already and need not to be defined by the user.

- 3-phase harmonic voltage and current distribution allowing an unbalanced harmonic load flows to be carried out.

- Harmonic current sources can be associated to every load, to any SVC (TCR injection) and to any rectifier or inverter. Harmonic voltage sources can be modeled using the AC voltage source model or the PWM AC/DC converter model. The build-in rectifier models inject the spectrum of ideal 6-ulse rectifiers if no other definition has been made.

- **DIgSILENT *PowerFactory*** supports any type of characteristic harmonic, un-characteristic harmonic (even harmonics etc.) and non-integer (inter-) harmonics. Also unbalanced harmonic sources (e.g. single-phase rectifiers) are fully supported. The analysis of inter-harmonics or unbalanced harmonic sources is based on a complete abc-phase network model.

- Transformer phase shifts are completely represented why 12 pulse rectifiers can be modeled correctly using 6-pulse rectifiers and transformers with the necessary vector groups.

- **DIgSILENT *PowerFactory*** calculates all symmetrical and asymmetrical harmonic indices for currents and voltages, including harmonic current indices and harmonic losses, such as:

  - HD and THD
  - IT product
  - Harmonic losses
  - Active and reactive power at any frequency
  - Total active and reactive power, displacement and power factor
  - RMS quantities
  - Unbalance factors

  Results can be represented:

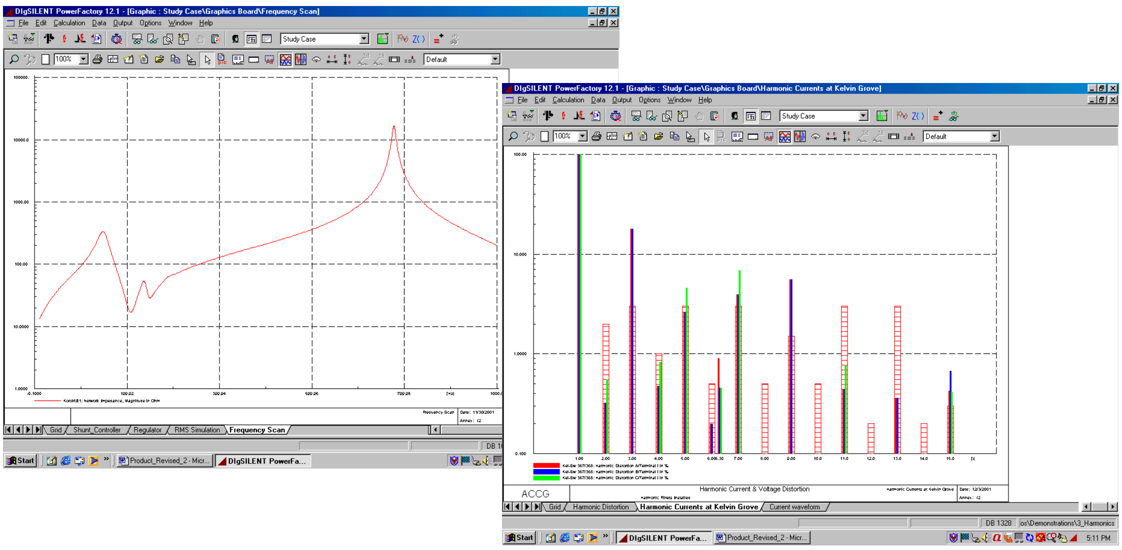
  - In the single line diagram (preferably total harmonic indices)
  - As histograms (Frequency domain)
  - As waveform (Transformation into the time domain)
  - As profile (e.g. THD versus bus bars)

- Frequency dependent representation of network elements such as lines, cables, two and three-winding transformers, machines, loads, filter banks etc. for considering skin effects.

Frequency Scan

The frequency scan performs a continuous analysis in the frequency domain. The most common application is the calculation of self- and mutual network impedances for identifying the resonance points of the network.

- All impedances are calculated simultaneously in the same run. Since **DIgSILENT PowerFactory** uses a variable step size algorithm, the calculation time of frequency scans is very low while the resolution around resonance points remains very high (typically 0.1 Hz).
- **DIgSILENT PowerFactory** also supports series voltage sources with which it is possible to identify possible series resonance points of the network (important for subsynchronous resonance studies).
- Frequency scans can either be performed with the positive-sequence network model (very fast) or the complete three-phase abc-network model.
- Calculation of self- and mutual network impedances
- Calculation of voltage amplification factors
- Impedance plots may be realized in either Bode, Nyquist or magnitude/phase forms.
- Support of flexible, user-defined libraries for voltage and current sources as well as for indices

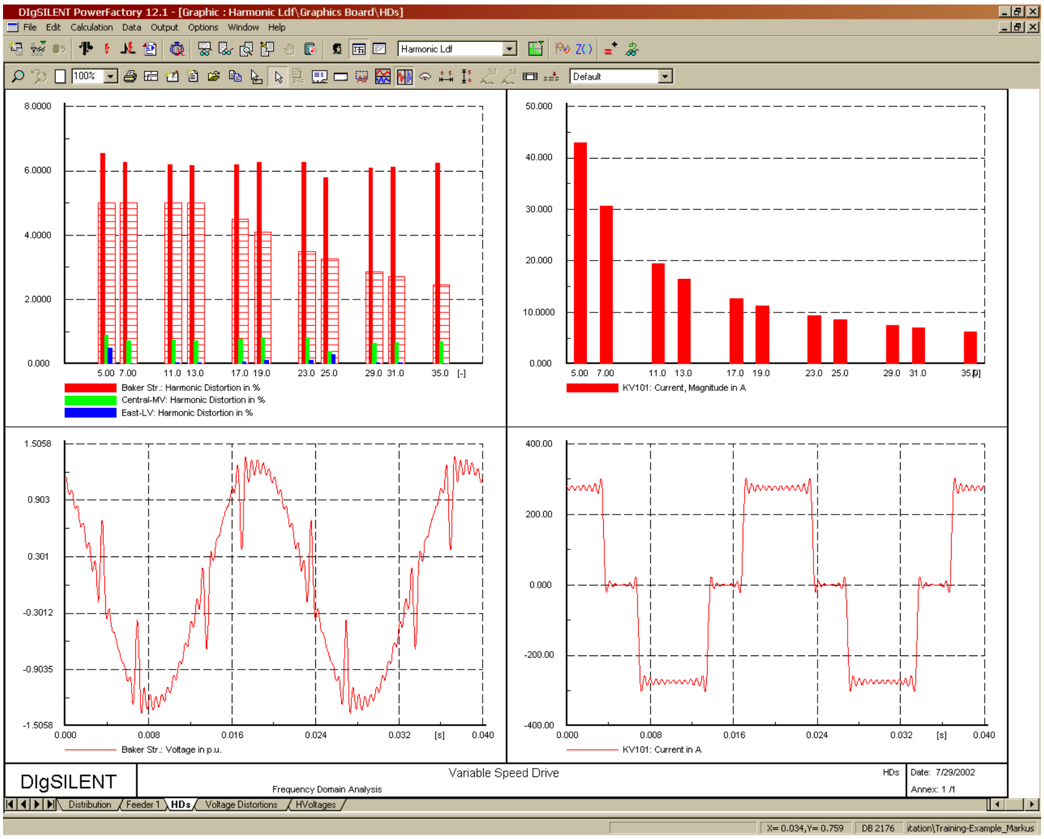


Network Modeling

Skin effect is considered by associating frequency characteristics to line or transformer resistances and inductances. These characteristics can either be specified by setting the parameters of a polynomial expression or by entering the characteristic point by point using tables. **DIgSILENT PowerFactory** uses cubic splines or hermite polynoms for appropriate interpolation.

- **Lines** are modeled either by approximate PI sections or the fully accurate **distributed parameter line model** that should always be used for long lines or high frequency applications. Skin effect can be included in both line models.

- **Filters** can either be specified by so-called "Layout" parameters or by "Design" parameters. "Layout" parameters are typically the rated reactive power, the resonance frequency and the quality factor. Design Parameter are the actual values of R, L, and C.



Ripple Control Signals

DIgSILENT PowerFactory provides full support for analyzing and dimensioning ripple control systems. Series and parallel coupling of ripple control systems can be modeled including all necessary filter elements.

- The level of the ripple control signal in the entire network is calculated and reported in the single line diagram, output window or the browser.

Dimensioning of Filters

DIgSILENT PowerFactory features a special, easy-to-use function for the dimensioning of all kind of filters. All relevant voltages across all components are calculated and available in the "Filter Sizing" report.

13. System Dynamics and EMT Simulation

DIgSILENT PowerFactory provides a basic simulation kernel, which, together with a comprehensive model library and a graphical, user-definable modeling system (**DIgSILENT** Simulation Language (DSL)), provides an extremely flexible and powerful platform for solving power system dynamic problems. Any combination of meshed 1-, 2-, and 3-phase AC and/or DC systems can be represented and solved simultaneously, from HV transmission systems, down to residential and industrial loads at the LV distribution levels. It includes transient analysis problems concerning short-, mid- and long-term dynamics, with adaptive step-sizes ranging from milliseconds to minutes.

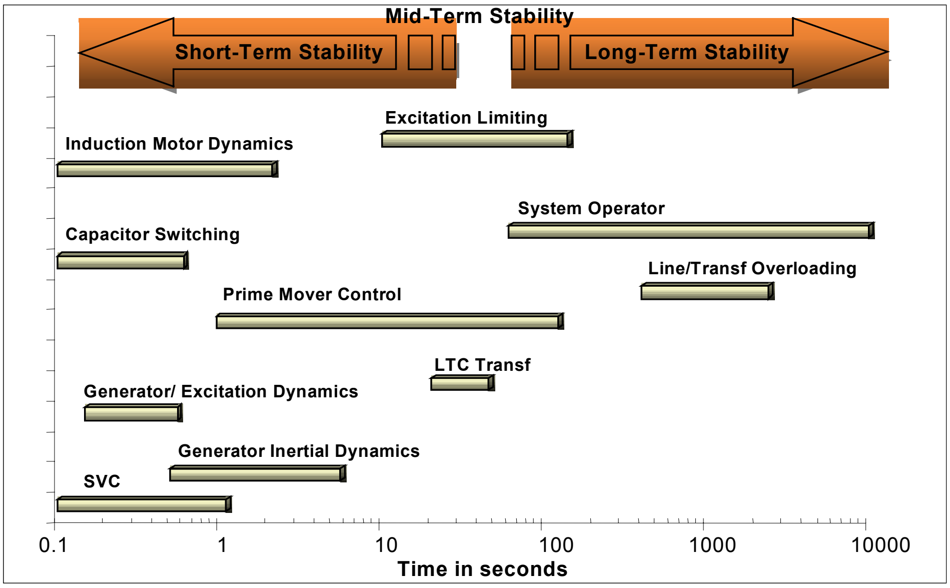
DIgSILENT PowerFactory features integrated analysis of classical stability problems using the RMS simulation mode as well as electromagnetic transients via EMT simulation. In other words, **PowerFactory** incorporates solution techniques making additional EMT software obsolete. This approach has many advantages over the classical application of two separate software systems such as:

- No duplication of data entry and case definitions
- User defined models need to be setup only once
- Absolutely compatible modeling features for RMS and EMT
- Easy cross-check of RMS results via EMT simulations
- No additional investments in other software and training

DIgSILENT PowerFactory is the leading software in power system dynamics. It's modeling flexibility and precision, it's numerical robustness and performance and especially it's comprehensive model library is providing everything required to implement all kind of dynamic studies in the most efficient and economic way.

System Dynamics (Stability, RMS)

At **DIgSILENT**, it is a principle policy to provide the most accurate simulation models and up-to-date solution algorithms, to enable analysis of the complete range of power system dynamic phenomena. On basis on fast and reliable adaptive step-size algorithms, the simulation kernel features excellent precision when solving short-, mid- and long-term stability aspects.



Time frames for power system stability studies

The dynamic simulation tools available to the user in **DIgSILENT PowerFactory** incorporate the following features:

- Calculation of initial conditions is carried out prior to the dynamic simulation, and is based on a solved load flow and other conditions such as power plant settings. Network representation and algorithm options are selected, with the following system representations available:

  - positive sequence only - the classical RMS representation for simulation studies
  - steady state a-b-c RMS representation, allowing any kind of asymmetrical fault;

- Highly accurate and adaptive integration technique for solving the AC and DC network load flow and dynamic model equations. This is combined with a non-linear electromechanical model representation to enable a high degree of solution accuracy, algorithmic stability and time range validity;

- Models for both solid and salient pole generators down to the sub-transient reactance and time constant level, with enhanced saturation effects, and Canay reactance incorporated;

- A sophisticated model for asynchronous machines that includes primary and secondary leakage reactance saturation, rotor resistance slip-dependency, and an additional single/double cage asynchronous machine with parameter identification;

- DC motor models, ASD systems (Adjustable Speed Drives), double-fed induction machine, PWM converter and other power electronic elements such as softstarter, inverter and rectifier;

- General load models where load inertia, bus voltage and frequency dependence is represented. A special lumped load model to accurately represent feeders containing a high percentage of motors in the load. The capability of modeling motor stall effects is included, and was developed on the basis of comprehensive system tests.

- The user can interrupt the simulation at any time, either manually or by scheduled interrupt time or automatically via interrupt conditions. When the simulation is interrupted, most **DIgSILENT** commands such as displaying or printing power flow results, checking the bus voltages, calculating eigenvalues or analyzing the controller status, etc. can be activated.

- By activating predefined fault types, or by accessing and modifying **DIgSILENT** variables any type of fault can be realized. Typical faults are:

  - line, transformer, feeder load and generator tripping
  - starting/tripping of synchronous and asynchronous machines
  - load shedding and shunt switching
  - application and clearing of faults at substations or along lines
  - change of controller set-points; controller failure
  - synchronization of isolated areas
  - injection of signals generated by a DSL device.

- The user can interrupt the simulation at any time, either manually or by scheduled interrupt time or automatically via interrupt conditions. When the simulation is interrupted, most **DIgSILENT** commands such as displaying or printing power flow results, checking the bus voltages, calculating eigenvalues or analyzing the controller status, etc. can be activated.

- Any **DIgSILENT** variable, or any quantity identified in the transmission network or dynamic models, may be selected for simulation observation or for later plotting within x/t or x/y diagrams or any other VI provided. In addition to these variables, the DSL algebraic expression interpreter and logical expression evaluator which can calculate any user defined quantity. Plotting files may be re-tained for re-plotting in comparison with subsequent runs

- Simulation monitoring window log of all simulation event procedures, which allows a detailed analysis of manually entered or automatically initiated events.

Long-term Stability

In many cases stability calculations must be run for long periods thus taking effects of slower control systems such as boiler control, network exchange control or transformer tap-changer control into account. Other applications are varying loads or applications of wind power where the impact of wind speed fluctuations must be analyzed. In such cases, short-term and mid-term dynamics have already reached steady state but slower transients are still being observed.

Long-term stability simulations require therefore adaptive step-size algorithms that allow an automatic variation of step-sizes within the range of milliseconds and several minutes without any decrease of precision or even manipulation of transient behavior.

DIgSILENT *PowerFactory* features a highly accurate long-term simulation algorithm with precise, event-controlled integration step-size adoption.

RMS Simulation with a-b-c Phase Representation

The a-b-c phase, steady state component representation of the power system, allows the fundamental frequency analysis of any asymmetrical fault combination, including single and double phase line interruptions. This representation is valid for electromechanical transients and 1, 2, and 3-phase systems with or without asymmetrical pre-loading. This system representation mode fully avoids tedious hand-calculations of equivalent fault impedance. It also allows for accessing any a-b-c phase quantity for plotting or precise modeling purposes (e.g. protection devices).

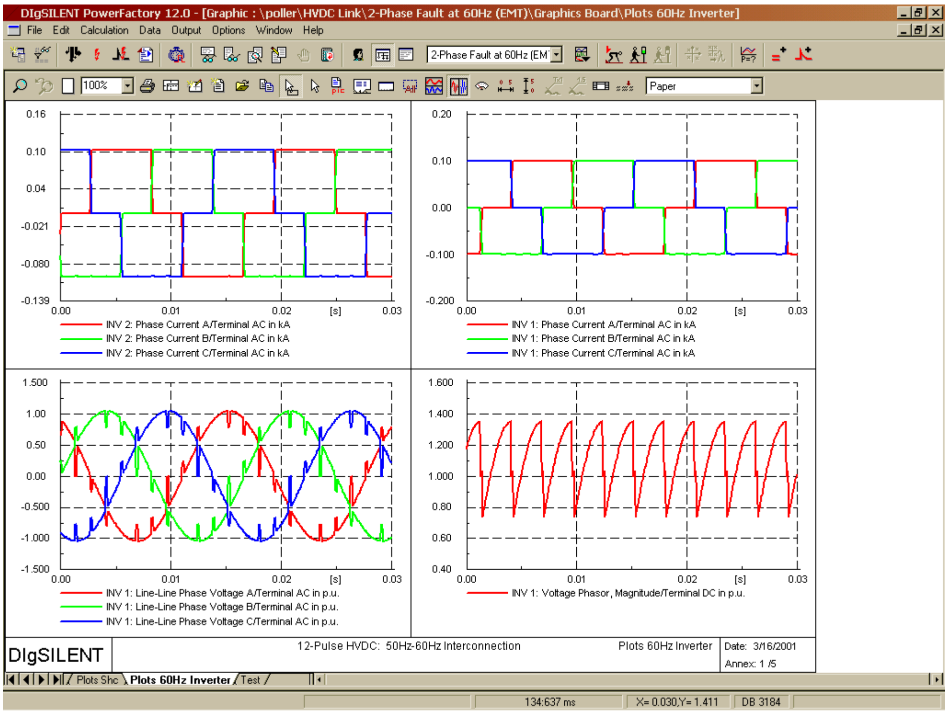
EMT Simulation

DIgSILENT *PowerFactory* also provides an EMT simulation kernel for solving power system transient problems such as switching over-voltages, ferro-resonance effects or sub-synchronous resonance problems. In the EMT simulation environment, the network model and associated devices are not represented as constant steady state impedances, but by the differential equations that govern their behavior. For transmission and distribution network lines and cables, the transient PI models as well as distributed parameter models are provided. Additional standard built-in models include:

- Transmission lines (according to tower layout), distribution network lines and cables
- Passive RLC branches, filters and sources
- 2 and 3 winding transformers for 1, 2 or 3 phase systems, including saturation effects
- VT, CT and PT models
- Series capacitor, MOV's and bypass switches

- HVDC valve groups (6 and 12 pulse Graetz bridge configurations) and other FACTS devices such as SVC's, UPFC's and TCSC's
- Circuit breaker models

Special numerical integration methods have been implemented in **DIgSILENT *PowerFactory*** in order to avoid numerical oscillations caused by switching devices and other non-linear characteristics. The calculation of initial conditions is carried out prior to the EMT simulation, and is based on a solved load flow (symmetrical or asymmetrical).



The DIgSILENT Modeling Flexibility

DIgSILENT PowerFactory features an unmet flexibility for implementing user specific modeling needs. The basic flexibility level is realized via graphical object wiring diagrams – called Model Frames. They allow for a comfortable configuration of functional block relations using object signal connections. Any existing **PowerFactory** object can be plugged into such a "slot". Frames can be lumped and nested to any degree of complexity. Hundreds of objects such as power system equipment (e.g. busbars, generators, lines, transformers, motors), relays, relay components, CTs, VTs, measurement files, FFT devices, real time clock, RMS signal transducer, parameter identifiers, controllers, power plant control components, A/D converter, RPC links, result files or display objects are at the user's disposal. In cases where additional functions are required, such functions can be build using the DSL language.

The most critical and decisive factor for producing reliable steady state and transient calculation results is the accuracy and completeness of the applied system model representation. Methods for solving this task especially for stability analysis purposes, range from the traditional way of using software which allows interfacing of user-defined models at the FORTRAN level - typically via connection lists (e.g. PSS/E)- to the block-oriented approach which is based on the provision of predefined basic block macros, connected at the case definition level (e.g. NETOMAC, NEPLAN). In addition, most modern commercially available general purpose simulation tools can only be used for flexible and not specific system representation (e.g. SIMULINK). In most cases the above mentioned approaches do not cover the special characteristics of electrical power systems adequately requiring iterative solution techniques to be able to determine the initial AC/DC load flows and to solve nonlinear grid characteristics during the simulation process.

The DIgSILENT Simulation Language – DSL

Although **DIgSILENT PowerFactory** contains a comprehensive model library and powerful built-in functions, there are many cases in which the user may want to implement additional control options and calculation functionality. For these reasons, the **DIgSILENT** Simulation Language (DSL) was developed.

DSL allows the creation of any kind of static or dynamic multi-input/multi-output model. Typical applications are:

- Voltage controller and excitation systems
- Power system stabilizers (PSS)
- Primary and secondary controllers
- Prime mover units
- Motor driven machines
- FACTS controllers
- any type of protection device, such as: distance relays, undervoltage relays, over-current relays, load-shedding relays, unit trip devices, electronic motor starting devices (EMR).
- any comprehensive calculation procedure required in the control environment
- Supervisory control devices

To provide a flexible modeling and simulation tool that forms part of an integrated steady state analysis and stability program, a control system based simulation language was developed. The following main features of the **D**IgSILENT **S**imulation **L**anguage (**DSL**) are considered to be most relevant:

- ❑ The DSL simulation tool falls into the category of Continuous System Simulation Languages (CSSL) including a complete mathematical description of (time-) continuous linear and nonlinear systems. The DSL is dedicated to common control and logic diagrams leading to a non-procedural language as the sequence of elements could be chosen arbitrarily. In sum, a DSL model is directly convertible into a graphical block diagram representation.

- ❑ Provision of a flexible definition of macros, which can be: algebraic equations, basic control elements like PID, PTn or even complete physical subsystems such as HVDC valve groups or excitation systems. In addition, various intrinsic functions like "select, lim, limits, lapprox, picdrop", as wells as "interrupt procedures" are included.

- ❑ Provision of various formal procedures for error detection and testing purposes, e.g. algebraic loop detection, reporting of unused and undefined variables and missing initial conditions.

- ❑ Automatic calculation of initial conditions is supported – an important feature especially when complex, nonlinear equations must be solved iteratively.

- ❑ DSL models are interfaced on all DIgSILENT level functions such as load flow, fault analysis, stability analysis, protection coordination and harmonic analysis, etc. Therefore multi-level modeling is given for the different steady state descriptions and transient time domains (short/mid-term, long-term and electromagnetic).

- DSL models can be generated directly on the graphical level by drawing the "block diagram". Any "block" may contain another DSL model, a macro or any sequence of DSL syntax. The DSL-editor will then generate the DSL description automatically and will also provide direct model testing functions such as eigenvalue analysis or step-response tests.

DSL Implementation

The DSL is a semi-independent module that is appropriately linked to the program kernel via the graphical interface - Model Frames (FMs). A FM is drawn in form of a block diagram that defines the "wiring" of the different functions required. The blocks can be understood as "slots" which are used to "plug-in" the appropriate models. The definition of frames is completely flexible featuring e.g. the definition of relay frames, plant frames or any other functions.

- **Signal input and output channels:** Any variable defined within the kernel (actually more than 5000) or a DSL model can be accessed in a read-and-write mode.

- **Interrupts:** Conditions derived by DSL models can cause interrupts to be sent to the program kernel where they are then scheduled within the event queue.

- **Output and Monitoring:** Conditions may trigger an output to be displayed on simulation monitor and stored in the simulation log file.

Advanced Features

- DSL models feature the direct interaction with external processes such as DAQ interfaces, SIMULINK modules or other software systems.

- Procedures written in C++ code can be directly linked via appropriate interface mechanisms.

- The numerical integration of DSL models, interrupt scheduling and input-output signal processing is handled automatically by the program kernel. In addition, if the output of a DSL model is an electric current that is added to the appropriate total bus current - which is the case if a load or generator model is created - all Jacobean elements necessary for static analysis like load flow and for the iterative simulation procedures will be calculated automatically.

Interpreter versus C++ Code

DSL model definitions are included in the DSL model library using their native language. This method can be compared to procedures used in conventional programming (e.g C, Pascal or FORTRAN). The main difference however, is that DSL does not require any compiling or linking procedures as DSL works like an interpreter, building up an **RPN** list (**R**everse **P**olish **N**otation) which is then processed automatically during runtime. Although DSL model interpretation is slightly slower than a compiled code in terms of execution times, the process of model development and testing is significantly faster than code compiling which requires linking and program reloading.

In order to cut down the DSL model execution times, an optimised DSL to C++ cross-compiler is also available, featuring the generation of dynamic link libraries (DLL) which is automatically loaded during program start-up, respective run time initialisation or directly re-loaded during program execution. With this option the user can implement self defined models on all calculation levels including network branch and bus elements *with its maximum possible execution speed*.

Parameter Identification

Built-in system identification and general optimization procedures provide an easy and accurate method to perform model parameter identification on the basis of system tests and field measurements. The *PowerFactory* identification tool is applicable for parameter estimation of multi-input multi-output (MIMO) systems, which are described by any type of nonlinear DSL model. The identification procedure itself is fully integrated in the graphical frame definition and block diagram level and also features parameter estimation of integrated models which forms part of a power system model such as loads or generators.

The provided optimization procedures are highly generic and can also be used for optimally tuning parameter such as PSS settings according to defined model response functions.

Eigenvalue Analysis

The **DIgSILENT PowerFactory** modal analysis tool features small signal analysis of a dynamic multi-machine system. System representation is identical to the time domain model. It covers all network components such as generators, motors, loads, SVS, FACTS, or any other component used for the system representation including also controllers and power plant models.

The calculation of eigenvalues and eigenvectors is an extremely powerful tool, e.g. for low-frequency oscillatory stability studies, PSS tuning, determination of interconnection options and basic parameter, and is a natural complement to the time domain simulation environment. It also allows for the computation of modal sensitivities with respect to generator or power plant controllers, load characteristics, reactive compensation or any other dynamically modeled equipment.

Eigenvalue analysis is with **DIgSILENT PowerFactory** performed in an easy, well-defined, and almost automatic procedure. The calculation steps are described as follows:

- Based on a converged and adjusted power flow, the modal analysis starts with the calculation of the systems initial conditions; alternatively any interrupted status of a time domain simulation could be used as initial condition.

- The system A-matrix is constructed automatically for the complete system (including generators, general loads, predefined system plant and controller models as well as DSL-devices). Therefore the overall system representation of the homogeneous form is:

  $$d\underline{x}/dt = A\ \underline{x}$$

- System and model linearization - incl. user defined models - is performed by iterative procedures. Limiting devices are disabled automatically. The representation of the network model is equivalent to the simulation model, allowing a direct comparison between time domain simulations and modal analysis results.

- System order reduction is automatically performed for zero rows and columns. This may occur, if a time constant or a gain has been set to zero.

- All eigenvalues are calculated and listed in their appropriate order. Based on the calculated eigenvalues and eigenvectors, the normalized participation matrix for the system oscillation is computed and the oscillation vectors for all modes are displayed graphically.

DIgSILENT PowerFactory can deal with multiple eigenvalues and eigenvectors which is an important feature when identical units are operated in parallel.

Depending on the program version, the resultant system A-matrix may have an order of up to 2500 and more - and hence may describe more than 250 machines modeled in detail and thus resulting in a correct damping pattern. If a system with a higher order is being analyzed, the application of the **DIgSILENT** selective eigenvalue analysis is recommended.

14. Transient Motor Starting

The motor starting function makes use of the PowerFactory stability module by providing a pre-configured shortcut for easy-to-use motor starting analysis. The motor starting is initiated by just selecting the respective motors within the single line diagram and initiating the motor starting calculation via the appropriate mouse-click. A complete symmetrical or asymmetrical AC/DC load flow will be computed prior to the motor starting event, Pre-selected and pre-configured Virtual Instruments (VIs) are automatically created and scaled.

- Consideration of complex motor models with build-in parameter estimation fully covering high precision modeling effects. A comprehensive library of low voltage, medium voltage and high voltage motors is provided;

- Typical motors supported are: single- and double cage asynchronous machines, squirrel and slip-ring motors, double-fed induction machine, synchronous motors;

- Access of model library for of build-in motor driven machine characteristics with flexible user-modeling support;

- Support of various starting methods such as direct start, star-delta starting, variable rotor resistor, thyristor softstarter, transformer softstarter, variable speed drives, etc.; start from any rotational speed;

- Full representation of generators with exciter/AVR model support on basis of build-in models (e.g. IEEE models) as well as user-defined models via the DSL approach; consideration of protection devices such as under-voltage protection, over-current protection our automatic restarting relays (EMR) or transformer OLTC;

Compared to the more complex dynamic simulation approach, Transient Motor Starting simulation is performed by assuming constant grid frequency (prime mover dynamics are not considered). Consequently, in cases where grid frequency varies significantly, the Dynamic Simulation Functions must be used.

15. Low-Voltage Network Analysis

DIgSILENT PowerFactory integrates enhanced features especially designed for analyzing low voltage networks. These functions enable the user to:

- ❑ Define loads in terms of number of customers connected to a line;
- ❑ Consider load diversity;
- ❑ Perform a load flow analysis that considers load diversity for calculating maximum voltage drops and maximum branch current
- ❑ Perform an automatic cable re-enforcement
- ❑ Voltage drop and cable loading analysis
- ❑ View feeder plots and perform feeder load scaling

Low voltage analysis of complex meshed systems is a standard feature with **DIgSILENT PowerFactory**. Neutral current caused by unbalanced single-phase loading and load diversity to various sources are statistically calculated to represent a realistic network.

Stochastic Load Modeling

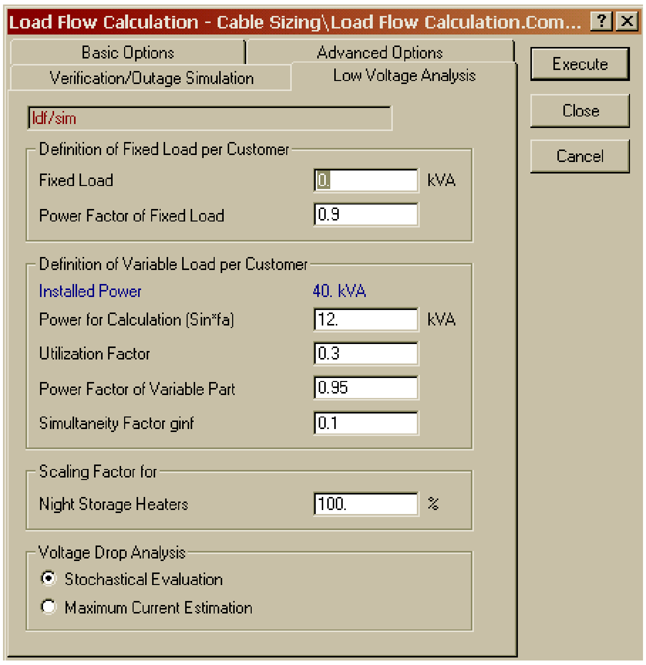
On the basis of defined "Customer Units" the user may specify a number of customers connected to a line. When performing a load flow, the load per unit customer is defined either by:

- Power per customer unit
- Power factor
- Coincidence factor for an infinite number of loads ("simultaneity factor")

In addition, the user may select between two methods for considering the stochastic nature of loads, such as:

- Stochastically evaluation
- Maximum current estimation

The first method is the more theoretical approach that can also be applied to meshed network topologies. The "Maximum current estimation" only applies stochastic rules for estimating maximum branch flows. Based on the maximum current flow branch element, maximum voltage drops are calculated and added along the feeder. However, this method has its limitations in case of meshed LV networks.

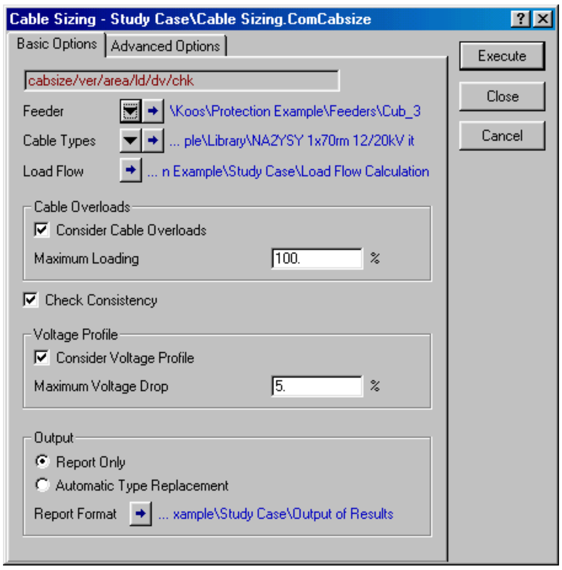


Upon successful execution of the load flow, maximum currents (Imax), maximum voltage drops (dumax) and minimum voltages (umin, Umin) are displayed in every branch element and at every bus bar.

The usual variables for currents and voltages represent here average values of voltages and currents.
Losses are calculated based on average values, max. circuit loading is calculated using maximum currents.

Cable Reinforcement

The cable reinforcement procedure determines the most cost-effective option for upgrading overloaded cables. Based on specific cable costs and voltage drop limitations, the corresponding cable is automatically selected and a respective report is issued.



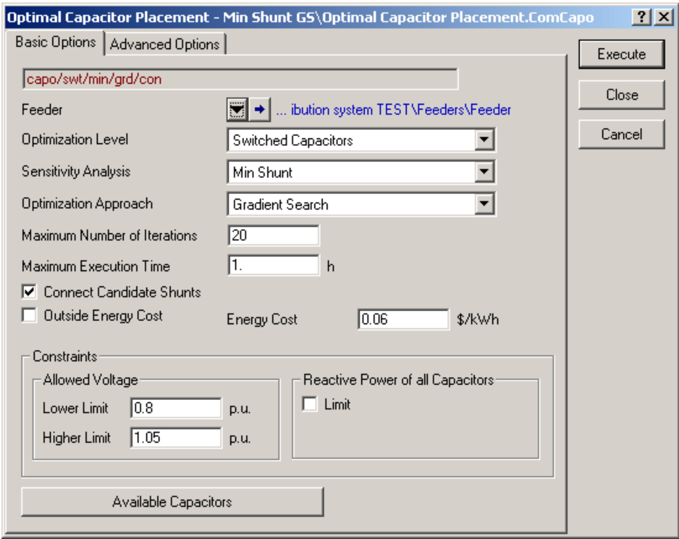
16. Distribution Network Optimization

DIgSILENT PowerFactory incorporates features to assist the user in distribution network optimization, and comprises of the following options:

- ❑ Optimal capacitor placement optimizing investment costs and losses
- ❑ Open tie optimization optimizing losses, supply reliability or any other user-defined function
- ❑ Cable reinforcement optimization (see also "LV Network Analysis Functions)

The user is also able to write is own DPL scripts for other user-defined optimization functions. Alternatively, DIgSILENT could prepare such scripts upon request.
Optimal Capacitor Placement (OCP)

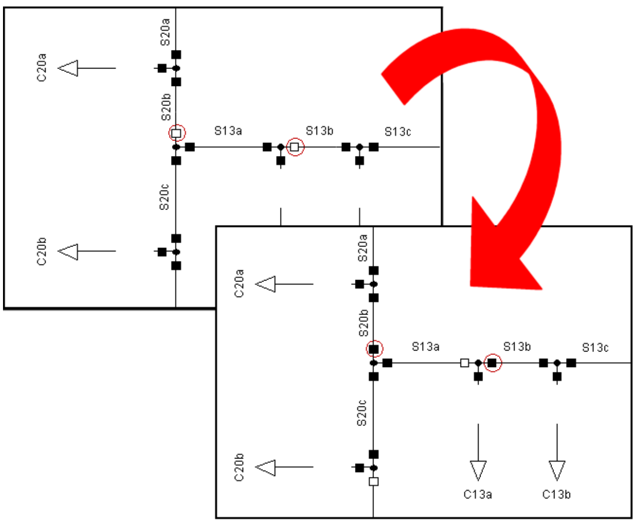
The **DIgSILENT PowerFactory** Optimal Capacitor Placement determines the optimal locations, types and sizes of capacitors to be installed in radial distribution networks. Using "Gradient Search" or "Tabu Search" methods, a cost function considering losses, cost of losses, capacitor installation costs, various load profiles, operational voltage limits and available capacitor types and costs is minimized over a period defined by feeder load profiles.



The result of the optimization procedure is a set of locations where capacitors should be installed, which type of capacitor(s) should be installed at each site, and whether or not a switched capacitor is suggested. Proposed capacitors are selected from a user defined capacitor library.

Tie Open Point Optimization (TOPO)

The **DIgSILENT *PowerFactory*** Tie Open Point command will minimize the losses in the network by changing the network topology, while preserving voltage and loading limits. The command is implemented as a DPL-script, which can be used as-is, or which can be adjusted to specific needs. The heuristic method used by the script is applicable to radial distribution networks.



- No parts of the system will be isolated
- No meshed structures will be introduced
- Any switch can be marked as an "optional open tie" and only user-defined optional Open Ties will be opened/closed.

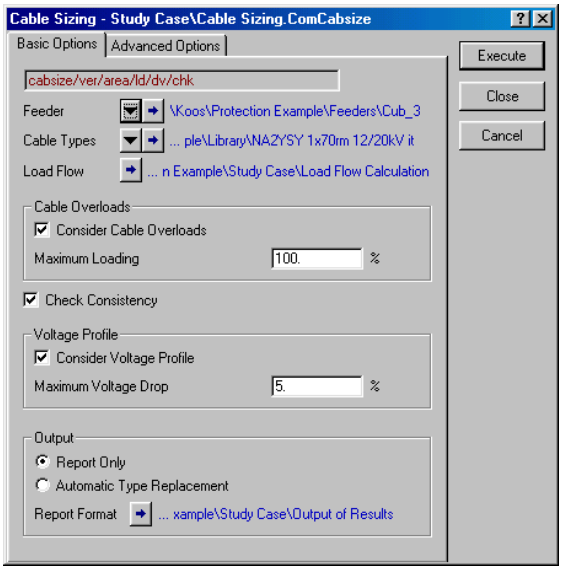
The default script uses a penalty function which optimizes losses when voltage and loading are in range. This penalty function can be easily adjusted to include specific loading limits for network components, short-circuit power limits, transformer tap limits, or any other condition.

Further features:

- New system topology can be accepted/rejected
- Topology changes are made visible in single line graphics
- All changes in switch positions, system losses and penalty functions are reported.

17. IEC Cable Sizing

The **DIgSILENT *PowerFactory*** cable reinforcement procedure determines the most cost-effective option for upgrading overloaded cables. Based on specific cable costs and voltage drop limitations, the corresponding cable is automatically selected and a respective report is issued. The automatic cable sizing procedure is performed in accordance with the IEC 364 Standard.



18. Reliability Analysis

Reliability calculations are essential for the evaluation and comparison of electrical power systems in terms of both design and operation. Although non-stochastic contingency analyses (for example (n-1)) are able to highlight obviously unacceptable operational events, they cannot rank these events in terms of either frequency or duration. The **DIgSILENT PowerFactory** Reliability analysis tool incorporates standard reliability assessment features together with sophisticated modeling techniques that enable all forms of reliability assessment to be carried out.

Failure model definition is achieved by defining mean yearly failure frequency and repair duration data. For lines and cables, this data is entered in per length terms. Detailed models are available for generators that enable derated states to be represented, with maintenance and common mode models also available.

Loads can be grouped into load areas, each of which is described by load forecast and growth curves. Load models are additionally available for hard-to-predict industrial situations, and each can be assigned its own interruption cost, from either the money/customer/interruption, money/kW/interruption or money/interruption functions.

All failure and load models can be represented either by the Markov method, where simple mean repair durations are modeled, or by the sophisticated Weibull-Markov method, where repair duration variance is additionally modeled. The Weibull-Markov model also has the unique property that annual interruption cost indices such as load and process (industrial) interruption costs can be calculated both analytically and quickly. Consequently, the **DIgSILENT PowerFactory** reliability analysis tool enables the comparison and justification of alternative investment proposals on a financial basis.

Finally, the results of all reliability assessments can be presented in text format, as user defined graphs, or within the single-line graphics environment. **DIgSILENT PowerFactory** offers both generation pool adequacy analysis ("Level I") as well as network adequacy analysis ("Level II" and "III"). The network reliability analysis can be carried out on the basis of a simple connectivity check (primarily meant for distribution networks) or on the basis of AC loadflow calculations (for bulk power system analysis).

Generation Pool Adequacy Analysis

Generation pool adequacy analysis compares the total available generating capacity with the load demand, regarding:

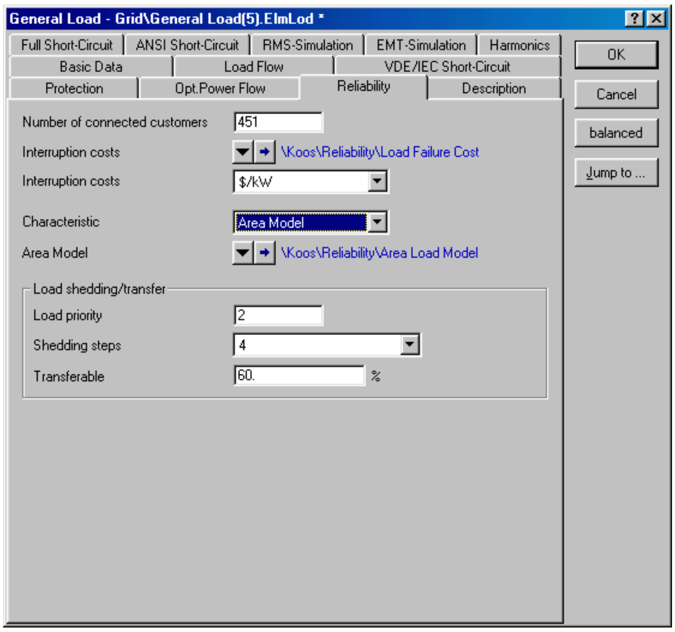
- Generator forced and planned outages (failures and maintenance);
- Generator derated states (partial outage);
- Stochastic load behavior

With this technique, sequential (Monte Carlo) analysis is used. The purpose of the generation pool adequacy analysis is to identify the generator ability to fulfill load demand in the case of an infinitely strong transmission and/or distribution system. Results from this analysis include:

- Loss of Load Expectancy (LOLE, hr/yr)
- Loss of Energy Expectancy (LOEE, MWh/yr)
- Loss of Load Duration (LOLD, hr/occ.)
- Loss of Load Frequency (LOLF, occ./yr)
- Expected Energy Not Supplied (EENS, MW)
- Typical generating capacity and reserve curves

Network Reliability Analysis

Distribution and bulk power network analysis are both carried out by the "Network Reliability" analysis function. This comprises of the assessment of interruption statistics for individual loads and busbars in distribution, sub-transmission and transmission systems. There are basically two approaches that can be taken:



- For a classical bulk power ("Level II") analysis, it is assumed that post-fault overloads may occur. A full AC load flow, incorporating basic generator re-dispatch and automatic tap changing, is used to analyze post-fault system conditions. Additional load transfer and/or load shedding may then be simulated.

- For a classical distribution ("Level III") analysis, it is assumed that contingencies will not lead to component overloading in the system. This can only be assumed in distribution systems. Without the overload analysis and alleviation functions incorporated, the analysis time can be considerably reduced.

The network reliability assessment considers:

- forced outages and subsequent repair of all primary network equipment
- generator dispatch and realistic load curves
- basic protection lay-out
- load priorities

For both bulk power and distribution system analyses, a realistic Failure Effect Analysis (FEA) is performed for all analyzed single and multiple contingencies. The FEA simulates both the automatic and manual reactions to faults of installed protection and of the system operators during each reliability assessment. The FEA can be checked and fine-tuned in an interactive way to exactly match the real system and operator reactions.

The FEA comprises:

- Automatic fault clearance by protective devices
- Automatic or manual fault isolation
- Automatic or manual power restoration by network reconfiguration
- Overload alleviation by optimized load transfer and load shedding, using both load priorities and load shedding properties.

Network reliability assessment can be executed for any contingency level (i.e. single order contingencies and 2 or more overlapping failures), for specific types or failure selections, and station configurations. A special "FEA mode" (Failure Effect Analysis) is also available which indicates all actions performed by the FEA functions for specific contingencies. The "FEA mode" was added to further increase calculation transparency, as it allows a detailed checking of the network reconfiguration activities during each assessment.

The following indices are calculated by the "Network Reliability" analysis assessment:

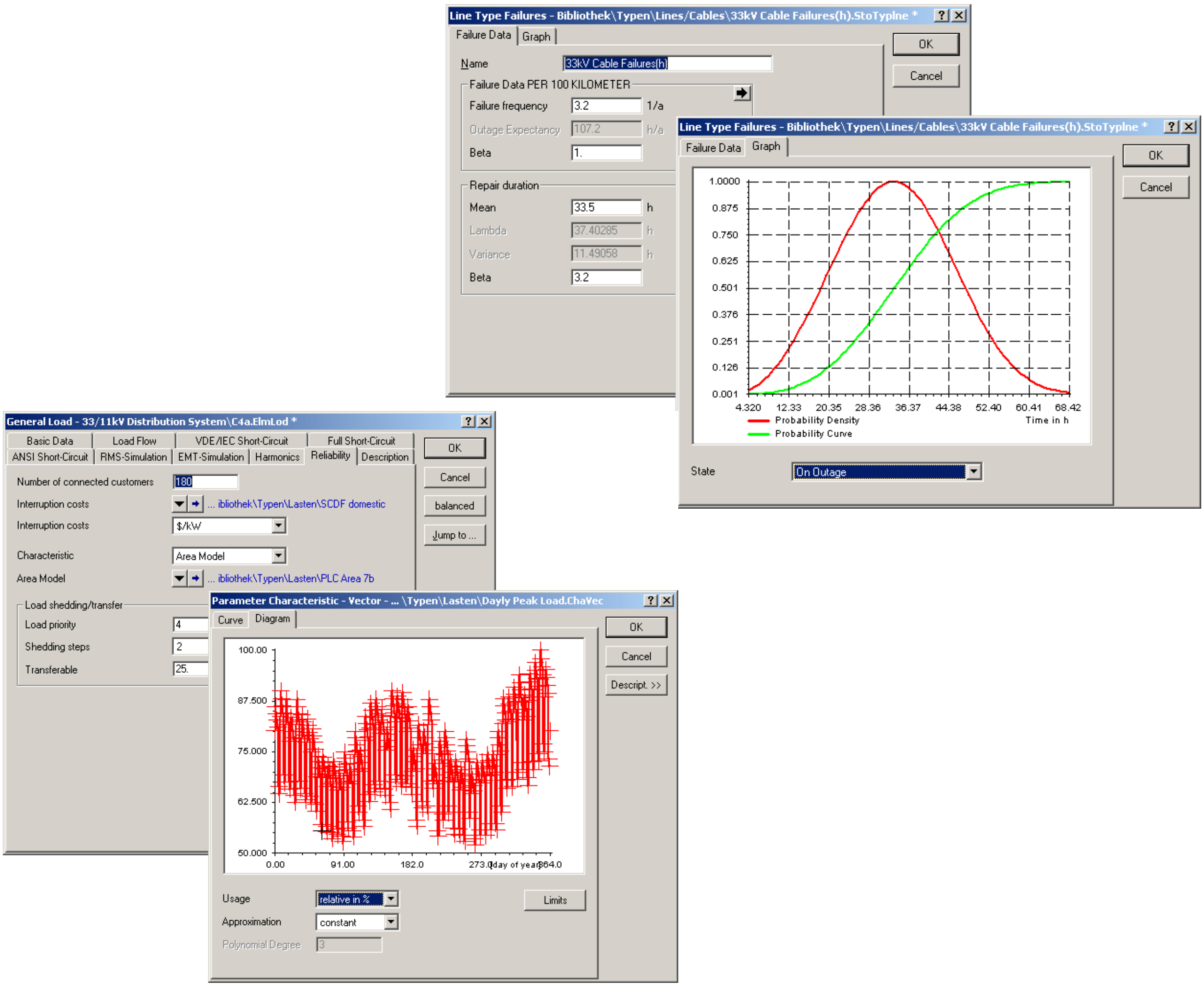
For loads:

- ❑ Average Interruption Duration (AID, hr)
- ❑ Load Point Interruption Time (LPIT, customers*hr/yr)
- ❑ Load Point Interruption Frequency (LPIF, customers/yr)
- ❑ Load Point Energy Not Supplied (LPENS, MWh/yr)
- ❑ Load Point Expected Interruption Costs (LPEIC, M$/yr)
- ❑ Average Customer Interruption Frequency (ACIF, 1/yr)
- ❑ Average Customer Interruption Time (ACIT, hr/yr)

The ACIF and ACIT are 'per customer' indices, while the LPIT, LPIF, LPENS and LPEIC are summations for the number of customers at the aggregated load model.

For busbars:

- ❑ Average Interruption Duration (AID, hr)
- ❑ Yearly Interruption Frequency (LPIF, 1/yr)
- ❑ Yearly Interruption Time (LPIT, hr/yr)



19. Production Planning

DIgSILENT PowerFactory can be utilized for production planning, through determination of optimal unit commitment and economic dispatch for both hydro and thermal generation systems. This is performed on the basis of integrated load and unit availability scales. The basic characteristics of this analysis option are:

For Thermal units/plants:

- Unit availability incorporating minimum and maximum run conditions, and power output limitations
- Maximum and minimum energy production during a planning period
- Minimum plant up and down times
- Power output gradients
- Prohibited operating zones
- Imposed power output

For Hydro units/plants:

- Unit availability incorporating minimum and maximum run conditions, and power output limitations
- Minimum and maximum reservoir levels
- Prohibited unit loading points
- Maximum and minimum discharge during a planning period and imposed water discharge for irrigation purposes
- Water transit times for coupled reservoirs
- Imposed power output

General

- Network control and reserve requirements (active power)
- Reliability levels and reserve policies
- Power exchange limitations, costs, tariffs, etc.

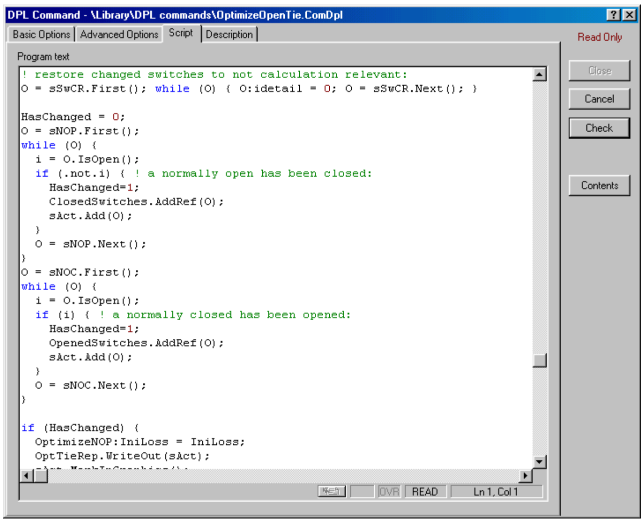
Special characteristics are available for the determination and consideration of spinning reserve requirements, such as:

- Active power control margins.
- Spinning reserve requirements that consider the individual transient spinning reserve release characteristics.
- Reactive (optional) and active power requirements including control capability margins and operational restrictions (e.g. reactive power required for large motor starting, reserve for covering units trips, separation of areas).

20. DIgSILENT Programming Language (DPL)

The DPL-Programming Language, offers a flexible interface for automating tasks in the **DIgSILENT PowerFactory** program. The DPL scripting language adds a new dimension to the **PowerFactory** software by allowing the creation of new calculation functions. Typical examples of such functions are

- Transfer capability analysis
- Automatic protection coordination
- Specific voltage stability analysis
- Contingency - network impedance analysis
- Parametric sweep calculations
- Penalty factor analysis



The DPL Object Oriented script language is intuitive and easy to learn. The basic set of commands includes:

- flow commands like "if-then-else", "do-while"
- Input, output and reporting routines
- Mathematical expressions
- Execution of **PowerFactory** commands
- **PowerFactory** object procedure calls and DPL subroutine calls

The strength of the DPL scripting language can be characterized by the following keywords:

<u>Easy Development</u>
The small basic syntax allows for the quick creation of simple commands to automate tasks. Tasks like renaming objects, executing specific search and replace commands, post-processing calculation results and creating specific reports are just some examples.

<u>Transparency</u>
All parameters of all objects in the network models are accessible. DPL can be used to query the whole database and to process all user-input and result parameters without restrictions.

<u>Standardizing Commands</u>
The DPL language can be used to create new 'standardized' DPL commands that can be used over and over again. DPL commands allow for the definitions of input parameters and can be started for specific selections of objects. Proven DPL commands can be safely stored in DPL command libraries and be used from there without the risk of damaging the scripts.

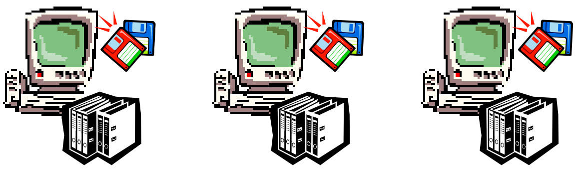
<u>Control</u>
DPL commands can configure and execute all **PowerFactory** commands. This includes the load flow and short-circuits calculation commands, but also the commands for transient simulation, harmonic analysis, reliability assessment, etc. New objects can be created in the database, and existing objects can be copied, deleted and edited. New reports can be defined and written to the output window, new graphs can be created and existing graphs can be adjusted to a user-defined selection or the current calculation results.

<u>Modularity</u>
A DPL command may contain other DPL commands which will then act as subroutines. This allows for the testing of subroutines as independent commands. Existing commands can be combined to quickly create more complex commands.

21. Software Installation Option

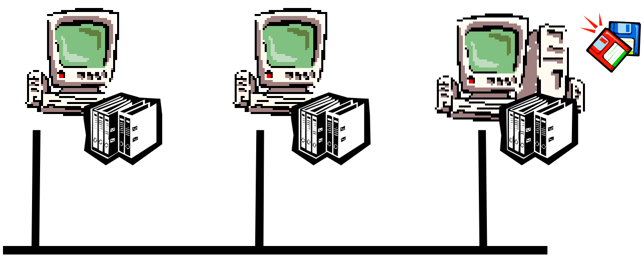
In addition to the classical, stand-alone single-user databases, multi-user database servers are optionally available. These enable different project teams to have partial or full access to project databases via user accounting and project access rules. In **DIgSILENT PowerFactory** three distinct configurations are available:

- Local Installation: Both, the program and database are installed locally on each computer.



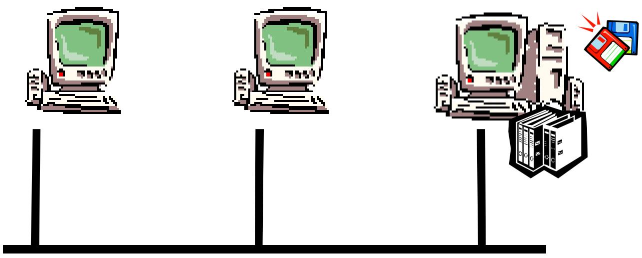
Typical local installation

- Network installation on a File Server: With this configuration the program resides externally on a file server but utilizes the local machine CPU for program operation. The database for each user also resides on each local machine or at any other location in the network.



Typical network installation on a file server

- Network installation on an Application Server: In this instance, the program and database both reside on an application server, with program execution and database updates occurring over the network. Access and operation of the PowerFactory software is made via Clients from each user terminal.



Typical network installation on a Server / Client environment

22. Compatibility to other Software Systems

Under certain circumstances, data compatibility with other software system is required. There are several reasons that could make such data transfer required:

- Users who have been using another power system analysis software have decided to migrate to the more powerful and complete **DIgSILENT PowerFactory** tool.
- Users who need to consider the neighboring systems which are still being analyzed with another software
- Data exchange with SCADA systems often require different formats, traditionally used and widely applied.

DIgSILENT PowerFactory comes with a feature that enables conversion of a variety of other formats. This is achieved using the **DOLE** syntax (**D**IgSILENT **O**bject **L**evel **E**xchange), which is essentially a flexible object-oriented ASCII interfaces with external database structures. Therefore, conversions are typically implemented via "OtherToDOLE" processors. As DOLE is supporting system data, graphic information as well as execution commands, import functions are in most cases generating compatible structures. The conversion process itself is performing a detailed and in-depth check of data and structures according to stringent data quality criteria.

Foreign file input via DOLE is supported for several versions of the following software systems: NETCAL, NEPS, PSS/E, PSS/U, Adept, NEPLAN and DVG.

As the DOLE input format is very generic, it can also be used to implement any user-defined conversion routine for other third party software incl. SCADA and GIS interfacing.

23. DIgSILENT PowerFactory Connectivity

DIgSILENT PowerFactory has the ability to interface directly with a number of external programs and hardware structures, such as GIS (Graphical Information Systems) and SCADA (Supervisory Control And Data Acquisition) systems. Additionally, A/D interfacing capability with the **PowerFactory Monitor** monitoring system is also possible.

The **DIgSILENT PowerFactory DOLE** software was developed in part to allow data conversion from programs, but also to meet the increasing demand for interfacing with GIS and SCADA systems. The **DOLE** structure is quite simple and allows users to custom design their own interface protocols, which enables compatibility with any number of SCADA and GIS systems.

SCADA Interface

Interfacing with **SCADA** gives direct access to dynamic and/or static SCADA data, allowing both real time system analysis and incident analysis from previous snapshots. As DIgSILENT PowerFactory integrates topology processing already, interfacing can be made on a point to point relation using foreign database keys.

GIS Interface

DOLE can also be interfaced with any existing Graphical Information Systems (GIS). For this purpose **DIgSILENT *PowerFactory*** provides the user with an auxiliary **EXCEL** file that permits data conversion from the GIS to **DOLE** formats. Figure 10.1 illustrates a typical GIS to **DOLE** data conversion program.

Engine Mode

DIgSILENT PowerFactory may be operated as a background process in situations where it is integrated into GIS or SCADA systems. This capability also permits the remote control of **PowerFactory** via the GIS or SCADA system directly, in what is called "Engine Mode". The basic advantages of this approach are summarized as follows:

- Engine Mode is an in-built feature available in all **DIgSILENT PowerFactory** package configurations, at no extra cost.
- All **PowerFactory** functionality is available in Engine Mode.
- Simple integration with the GIS or SCADA system.
- **PowerFactory** software upgrades will not require complex re-integration procedures on the source code level.
- The **PowerFactory** MMI can be activated for data maintenance, operation and display purposes at any time in Engine Mode.

A/D Interface Capability

The **DIgSILENT PowerFactory** A/D interface with the **PowerFactory Monitor** monitoring system, is the latest development in integrated operation supervision, fault recording and test analysis evaluation. This is achieved via the generic model frame and VI (Virtual Instrument) environments, and may be utilized to:

- Implement analog inputs with for up to 5 kHz per channel
- Perform signal normalization and correction
- Calculate RMS values and phasor quantities

- Realize soft-transducers for active power, reactive power, frequency, speed, frequency spectrum, system oscillation analysis and many other quantities
- Determine trigger conditions for fault recording
- Perform permanent monitoring
- Detect system oscillations
- Analyze and supervise connection conditions
- Direct interchange of signals with the model identification blocks.

24. DIgSILENT Support and Training

Training

DIgSILENT does not offer regularly scheduled training courses for the **PowerFactory** software; however special theoretical and application training is available, according to user requirements and timetables. Our training specialists can cover the complete range of power system analysis topics and **DIgSILENT PowerFactory** application training, including:

- Data organization and case management
- Steady state analysis (power flow and short circuit analysis)
- Protection coordination
- Harmonic power flow
- All aspects of stability calculations
- Enhanced system modeling for power plants, loads, generators, protection devices and controllers

Special training programs are available upon request, and may be carried out at the Gomaringen office or any user-specified location. All training courses may be optionally conducted in German, English or Spanish.

Maintenance

Fixed term software maintenance contracts are available for both 12 and 24-month periods. Additionally, these contracts may be structured with automatic extensions to the existing fixed term periods. All optional maintenance contract costs are available upon request to **DIgSILENT**.

25. DIgSILENT Consulting

DIgSILENT also offers a wide range of engineering services that can supplement your in-house expertise, specializing in the less common areas of power system engineering and analysis.

Operation Optimization

DIgSILENT has a broad knowledge of operation optimization, as well as trouble shooting experience in many areas of power system dynamics and control, such as,

- Spinning reserve optimization
- Optimal load-shedding concepts
- Network control and primary control
- Optimal PSS tuning and damping analysis
- Performance monitoring and fault analysis
- Implementation of system tests and identification (prime movers, AVRs etc.)
- Determination of simulation models
- Load measurements and parameter estimation
- Analysis and SSR and ferro-resonance problem solving
- Earthing and transient over-voltage studies
- Load forecasting
- Unit commitment and economic dispatch
- Optimal power flow
- Reliability assessment

Industrial Application

DIgSILENT has a long tradition and extensive experience in industrial system planning and optimization. The **DIgSILENT PowerFactory** software provides us with a high degree of solution accuracy and flexibility for studies of industrial power systems, and the following services are offered:

- Power quality analysis (harmonics, voltage sags, operational characteristics)
- System transient analysis (motor start-up, primary control, voltage control, over-voltages)
- ASD and LCI applications
- Protection coordination
- Reliability and security studies
- System tests and measurements
- Operational optimization
- Design review and system specification

System Planning

DIgSILENT offers a wide range of specialized engineering services relating to system planning and market liberalization, such as;

- Master plans
- Feasibility studies
- Conceptual design reports
- Unbundling and privatization
- Power purchase agreements (PPA)
- Power wheeling
- BOT/BOO schemes for power plants, transmission and distribution networks

- Grid code development
- Connection conditions and characteristics
- Generation, Transmission and Distribution Planning
- Technical economic evaluations
- Proposed HVDC and FACTS installation analysis
- Stability and reliability
- Protection concepts and setting optimization

System Tests

DIgSILENT also offers specialized expertise in the performance of system tests, test evaluations and plant modeling, such as;

- Analysis of system characteristics
- Secondary control performance analysis and optimization
- Determination of primary control parameter and spinning reserve capabilities
- Analysis of AVR and excitation control dynamics
- Definition and tuning of PSS parameters
- Over-voltage, SSR and ferro-resonance studies
- Load measurements and parameter estimation
- Analysis of system oscillations
- System model development
- Analysis of plant measurements and system identification
- DSL model development
- Model testing and verification
- Connection characteristics
- Evaluation of primary and secondary response characteristics
- Determination of harmonic penetration