DIgSILENT PowerFactory

Integrated Power System Engineering & Software

* Generation * Transmission * Distribution * Industrial

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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.

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

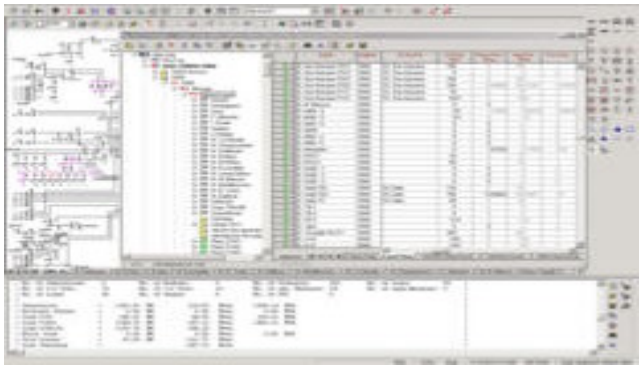
- Load Flow and Fault Analysis of complete AC/DC network representation, and allows meshed and mixed 1-,2-, and 3-phase AC and/or DC networks to be modeled.
- Low Voltage Network Analysis
- Distribution Network Optimization
- IEC Cable Sizing ● Dynamic Simulation
- EMT Simulation ● Eigenvalue Analysis
- System Identification ● Protection Analysis:
- Harmonic Analysis Reliability Analysis
- Production Planning
- 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.



3. General Concept

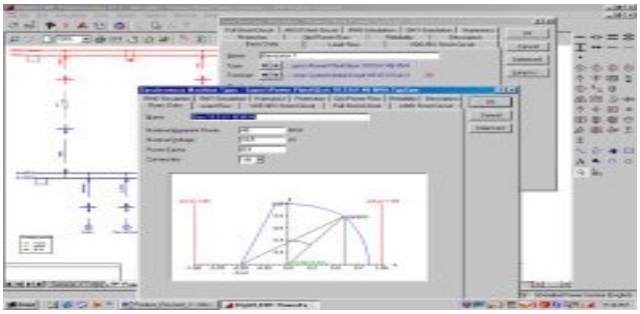
DIgSILENT PowerFactory comes with a number of advanced features introducing highest flexibility and providing best possible user support and quality assurance mechanisms.

- ***Functional Integration***
- ***Vertically Integrated***
- ***Database Integration***

4. Mode Of Operation

Windowing Operation

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



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

Introducing Intelligent Data Structures

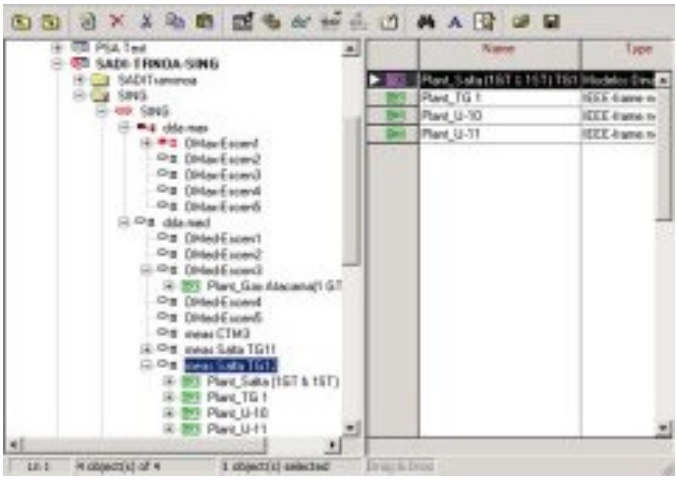
In order to minimize data redundancy, object data is split into Type and Element Data so that the same set of data can be used many times via type references. For most network objects such as cables, motors or relays, comprehensive libraries are provided allowing user access and maintenance on various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

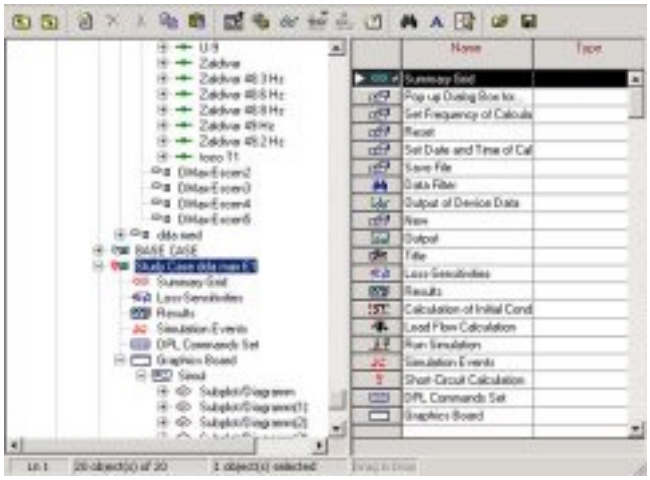
Libraries

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.

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.



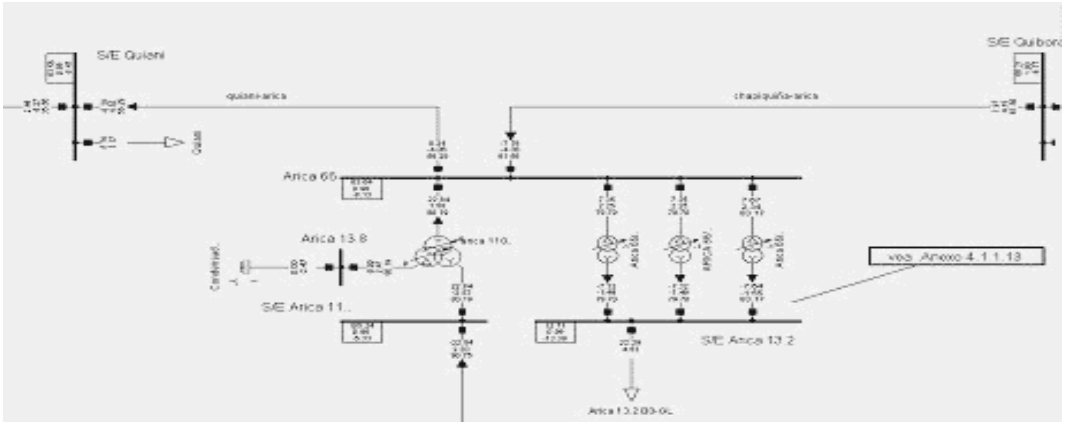


6. The Graphical Editor

Interactive Graphics

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

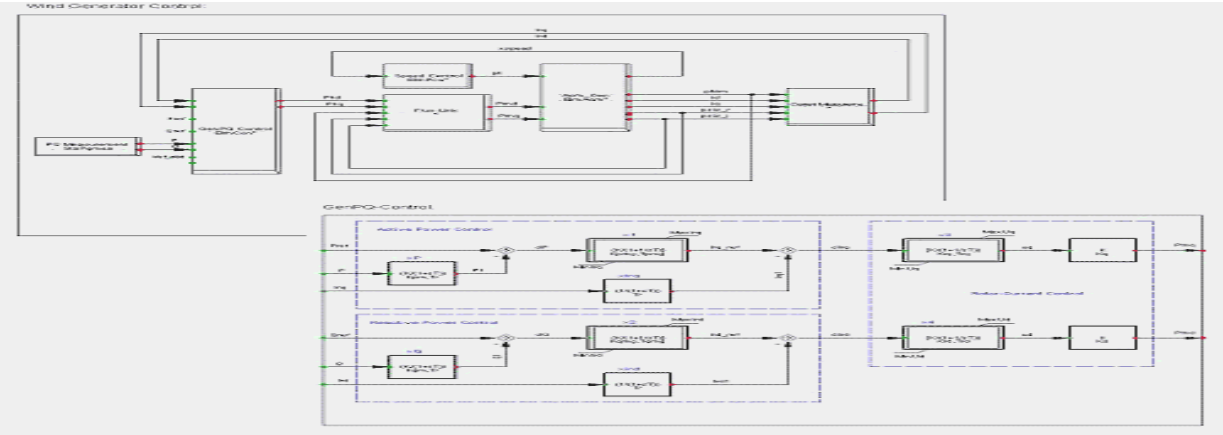
- Draw and modify electrical grids for integrated network and area diagrams, classic single line and substation configuration diagrams, with a configurable multi-layer network viewing and plotting capability;
- **Multi-Layer-Techniques**: view and operate several windows with different layers and grid 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.

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.

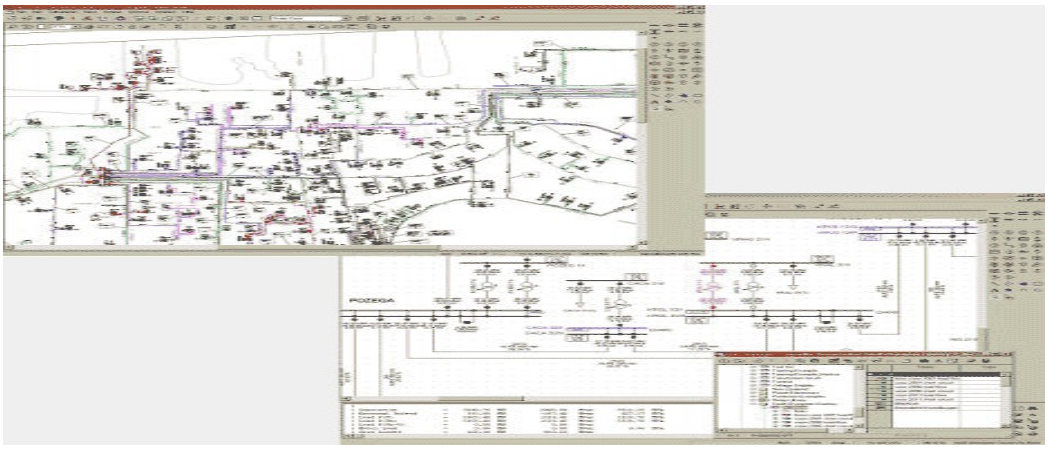
Graphical Documentation

Graphical interchange with other software systems via the Windows Meta File (WMF) and Bit Map exchange is available with high precision coordinates.

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 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.



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.

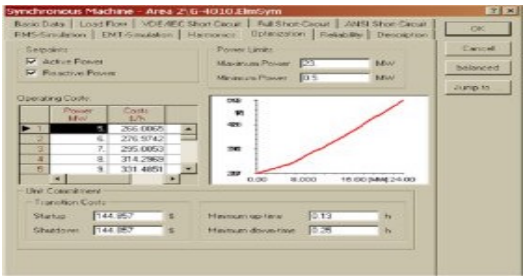
Feeder Analysis

9. Optimal Power Flow

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)
- Generator reactive power and stator current limits
- Transformer tap changer limits
- Bus bar voltage limits
- Generator active power and reserve 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 & 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.

Fault Analysis Results

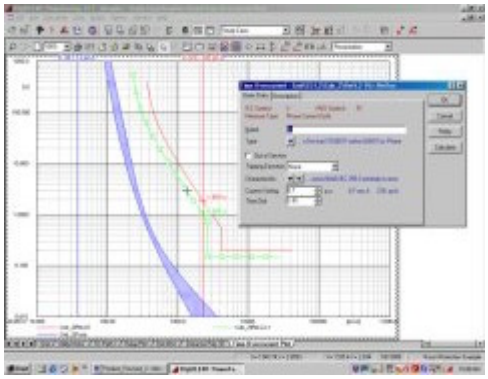
- Various reports may be produced, including detailed reporting on all short circuit levels for all faults, or alternatively, a specific report for one fault type. Special protection reports can also be generated to include impedance, current and voltage information.
- Display of any variable within 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

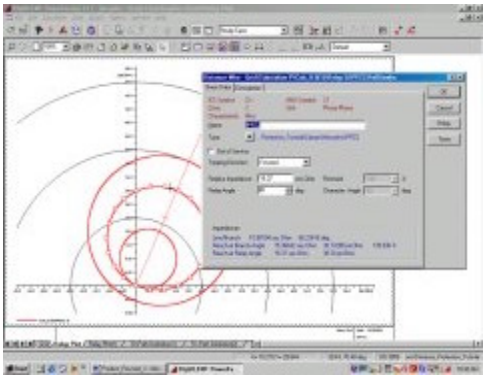
11. Protection Functions

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 overcurrents.
- 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.

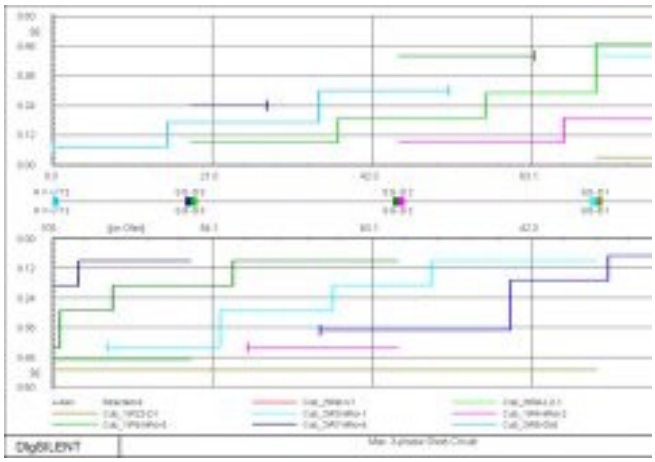
- Voltage relays for undervoltage, instantaneous voltage, voltage balance and unbalance.
- Additional devices include Breaker fail, Motor protection, Generator, and Out-of-step relays.
- Apart from the standard circuit breakers the model library contains Low voltage circuit breakers and Fuses

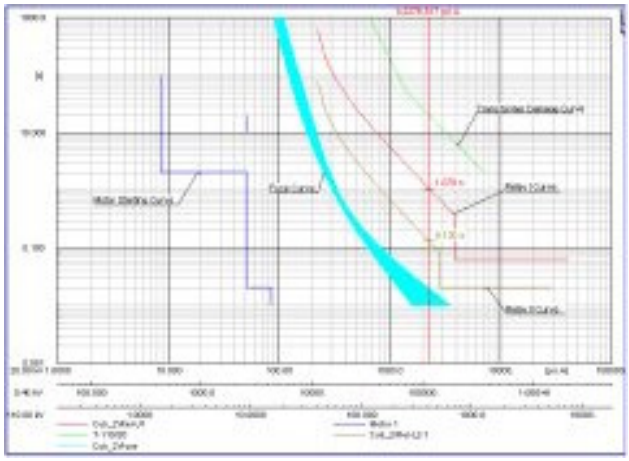
Additional to these protection functions and relays **DIgSILENT *PowerFactory*** provides further devices and characteristics for more detailed protection system modeling, such as:

- 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

Protection Co-ordination

Protection diagrams:





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.

Harmonic Load Flow

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.

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

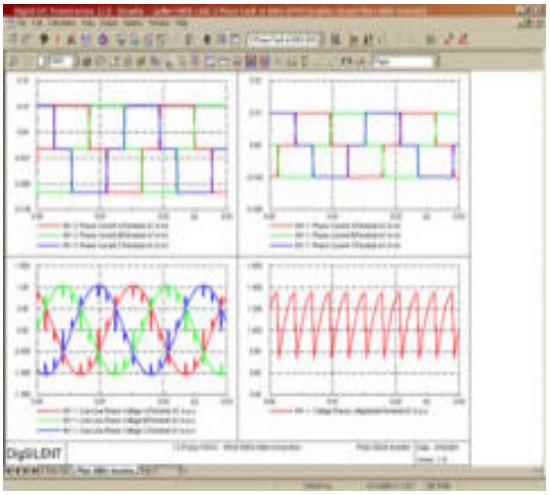
13. System Dynamics and EMT Simulation

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.

- **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.

- 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.

RMS Simulation with a-b-c Phase Representation & 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. 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 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 Passive RLC branches, filters and sources

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;

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

Stochastic Load Modeling : Power per customer unit ● Power factor ● Coincidence factor for an infinite number of loads .

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.

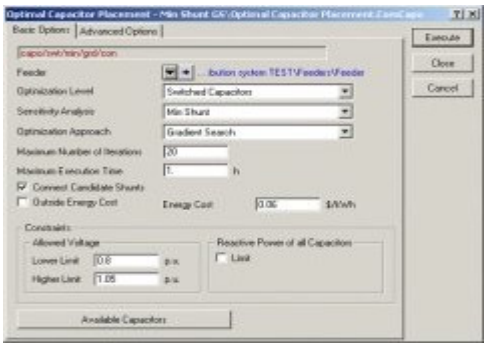
16. Distribution Network Optimization

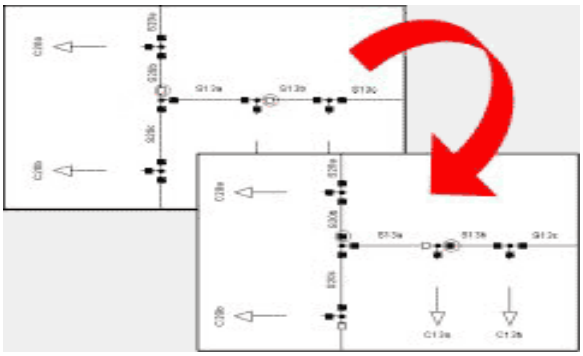
DIgSILENT PowerFactory incorporates features to assist the user in distribution network optimization, and comprises of the following options:

- 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 optimisation functions. Alternatively, DIgSILENT could prepare such scripts upon request.

Optimal Capacitor Placement (OCP)





Tie Open Point Optimisation (TOPO)

- 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 IEC Cable Sizing function of PowerFactory is calculating the current-carrying capacity of cables. The current-carrying capacity in PowerFactory is specified by two parameters. These are the nominal current and the rating factor. The nominal current of a cable is calculated from the construction of the cable (insulation, conductor, ...). The rating factor depends on ambient conditions like temperature and laying arrangement.

The calculation is based on IEC-364-5-523 electrical installation of buildings. Chapter 52 wiring systems, section 523 - current-carrying capacities. According to this standard the current-carrying capacity can be calculated for non-armoured cables having a nominal voltage not exceeding 0.6 kV/1.0 kV, only.

18. Reliability Analysis

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.

Generation Pool Adequacy Analysis

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

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

Network Reliability Analysis

The network reliability assessment considers

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

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 Failure Effect Analysis (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.

For loads:

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

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. 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
- Specific voltage stability analysis
- Parametric sweep calculations
- Automatic protection coordination
- Contingency - network impedance analysis
- 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"
- Mathematical expressions
- **PowerFactory** object procedure calls
- Input, output and reporting routines
- Execution of **PowerFactory** commands
- DPL subroutine calls

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

- **Easy Development**
- **Transparency**
- **Standardizing Commands**

22. 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.