



NV Compressors and Pipes

Optimization system for dispatching control

By Leonid Ostromuhov

July 2011

1	<u>Introduction and Concept</u>	3
1.1	Some High level functions using for compressors and gas networks	3
1.2	Concept of tools for the gas network optimization	
1.3	Concept of compressor tools Visualizer and Characterizer	5
2	<u>Design, dispatching, control, and optimization of gas networks and contracts</u>	6
3	<u>Graphicord-Gis as an operating program of the Network Optimizer</u>	7
3.1	The basic functions of Graphicord-Gis	8
3.2	Components	9
4	<u>Graphicord</u>	13
4.1	Overview	13
4.2	Symbol Designer	14
4.3	Net-Element Editor	14
4.4	Topoeditor	15
4.5	Organization of versions, scenarios and states of networks	16
4.6	GIS	17
4.7	Integration with external applications	17
4.8	Path Finder	17
4.9	Support of embedded spreadsheet format	19
4.10	Reports putting by Generator of tables and diagrams	20
4.11	Graphical Format Rules	21
4.12	Flexible user definable export and import	22
4.13	System Configuration	23
4.14	Benefits	23
5	<u>Compressor-Visualizer</u>	24
5.1	Uses	24
5.2	Some terms	24
5.3	Interfaces	24
5.4	Functions and benefits of Compressor-Visualizer	25
5.4.1	The main functions	25
5.4.2	Monitoring	25
5.4.3	Modeling and simulation of operating points of compressors and drives	25
5.4.4	Visualization of results of monitoring and modeling	25
5.4.5	Benefits	26
6	<u>The Optimization system</u>	26
6.1	Objective functions using in Graphicord-NPC	27
6.1.1	Operational optimization	27
6.1.2	Economic optimization	27
6.2	Variables using in Graphicord-NPC	28
6.2.1	Discrete (integer) variables	28
6.2.2	Continuous variables	28
6.3	Data model as entity-relationship model	28
6.4	Benefits	29

1 Introduction and Concept

1.1 Some High level functions using for compressors and gas networks

The High Level Functions that people use for monitoring, modeling, simulation, optimization and control of compressors and their drives, their uses and features, and the names of our tools are shown in Table 1. The cases where Wikipedia was cited for description of the aims and use, are marked with an asterisk.

Table 1. The High Level Functions, their uses and the names of our tools that people use for monitoring, modeling, simulation, optimization and control of compressors and their drives

	1	2	3
	High Level Function	Use and features	Our Tool
1	Condition monitoring (CM)	<p>It is the process of monitoring a parameter of condition in machinery, such that a significant change is indicative of a developing failure. It is a major component of predictive maintenance.</p> <p>Condition monitoring has a unique benefit in that the actual load, and subsequent heat dissipation that represents normal service can be seen and conditions that would shorten normal lifespan can be addressed before repeated failures occur. [*]</p>	Compressor-Characterizer, S. Parameter Monitoring as well as Characteristics Diagnostics
2	Vibration Monitoring / Vibration analysis / Compressor Diagnostics	<p>Measurements can be taken:</p> <ul style="list-style-type: none"> – Of casing vibrations – on machine bearing casings – Of the radial and axial vibration of the shaft – on the rotating shafts [*] 	--
3	Parameter monitoring and Performance monitoring (PM)	<p>It is a part of condition monitoring concerning parameters of operation.</p> <p>Measurements are required of physical quantities: temperature, pressure, flow, speed, displacement, according to the plant item. Absolute accuracy is rarely necessary, but repeatable data is needed. Calibrated test instruments are usually needed, but some success has been achieved in plant with DCS (Distributed Control Systems). [*] Performance analysis is often closely related to energy efficiency, and therefore has long been applied in steam power generation plants. In some cases, it is possible to calculate the optimum time for overhaul to restore degraded performance. [*]</p> <p>There will be monitored:</p> <ul style="list-style-type: none"> ✓ Machine characteristics; ✓ Operating points; 	Compressor-Characterizer – in full volume, Compressor-Visualizer using in its on-line mode provides the Performance Monitoring partially, without data saving in a relational database

		<p>✓ Parameters such as:</p> <ul style="list-style-type: none"> • Air temperature; • Exhaust gas temperature; • Power output; • Fuel gas or • Electricity consumed; • Efficiency, etc. 	
4	Characteristics Diagnostics – Monitoring and diagnostics of characteristics of the machines	<p>It is a new feature that we introduced on the market. It includes actualization and refinement of the characteristics of machines and the models on the base of industrial operational measurements. Determination of the actual parameters of the machines and their models is also included. These allows a permanent on-line operation of the following functions as</p> <ul style="list-style-type: none"> – Field testing and attesting of the .machines – Automatic evaluation of the state of machinery and its trends based on the collected measurements, the updated models and mathematical methods 	Compressor-Characterizer
5	Simulation of operating points of compressors and drives	<p>Economic and operational simulation of compressors and drives. As result, it provides a tabular and graphical visualization of their characteristics and operating points.</p> <p>Our tool Compressor-Visualizer is used in two options: (i) On-Line with a real data from DCS / SCADA; (ii) Off-Line with data taken from the plan, analysis, optimization, and contracts.</p>	Compressor-Visualizer
6	Load Sharing in a station	<p>Load control in a compressor station – optimal load sharing between machines.</p> <p>Our Load Sharing covers cases of operating compressors of all different types in a station. It presents a new feature on the market.</p> <p>The former available technologies cover properly only cases, where compressors are operated parallel and their power differs less than 7 – 12 %.</p>	The Station Optimizer – a Compressor-Optimizer
7	Optimization of the steady state of gas networks	<p>Economic and operational simulation and optimization of the steady state of gas networks.</p> <p>Our Network Optimizer consists of the optimization core called as ACCORD that is equipped with GRAPHICORD and Graphicord</p>	The Network Optimizer – ACCORD operating under Graphicord-GIS and Graphicord

		–Gis. The Network Optimizer provides the economic and operational simulation and optimization of the steady state of gas networks and compressor stations, flexible graphical user interface (GUI), support of database (DB), support of geographic information systems (GIS), and connection with process control system DCS/SCADA in a real time.	
--	--	---	--

1.2 Concept of tools for the gas network optimization

The general concept of tools for the optimization of gas networks provides for the following:

1. Optimization based on flow problems in networks with capacities
2. Optimization of general networks of any structure based on a steady-state simulation
3. Setting and solving operational, technological and economic problems and using operational, technological and economic objective functions, restraints and variables
4. Using models of varying degrees of accuracy according to the problems being solved
5. Simulation of flow, pressure and temperature in such technological systems as any on-shore and off-shore pipelines, compressor stations, compressors and drives of any type and of general structure
6. Representation, storing and visualization of initial data and results; characteristics, operating points and set-points of compressors and drives; in-takes, off-takes, and the corresponding contracts and operational agreements; technological and economic restraints
7. Flexible interface
 - 7.1. Graphical user interface (GUI)
 - 7.2. Relational database (DB) and files
 - 7.3. Geographic Information System (GIS)
 - 7.4. Distributed Control Systems (DCS)

1.3 Concept of compressor tools Visualizer and Characterizer

The general concept of compressor tools is to provide the following:

1. Simulation of compressors and their drives with a precision that is comparable to the accuracy of the measurements
2. Development of methods and software for the simulation that has precision, which is comparable to the accuracy of the measurements
3. Data interface that allows
 - 3.1. The use of modeling of compressors and drives for simulation, optimization, control, and supervision of state of machines, compressor stations and gas networks
 - 3.2. Communication with the process control systems DCS/SCADA for data reading of measurements and for data transmission of control parameters and their set-points
 - 3.3. Application of models and their parameters
 - 3.4. Application of the simulation software
4. Monitoring of performance, efficiency and parameters of machines as Performance Monitoring
 - 4.1. Saving the results of measurements and simulations, along with their time stamp in the data base
 - 4.2. Graphic and tabular representation of the measuring data and the simulation results

5. Actualization and refinement of the characteristics of machines and the models on the base of industrial operational measurements
6. Field testing and attesting of the machines
 - 6.1. Determination of the actual parameters of the machines and their models
7. Automatic evaluation of the state of machinery and its trends based on the collected measurements, the updated models and mathematical methods

2 The Network Optimizer for design, dispatching, control, and optimization of gas networks and contracts

Optimization system Network Optimizer is used for dispatching control, both for technological and contract control. The Network Optimizer includes the following (sub-) systems, s. Fig. 1:

1. Graphicord-Gis that is a management/operating program of the Graphicord-Suite
2. Graphicord that integrates besides others
 - 2.1. Means that often belongs to a control system and Distributed Control Systems (DCS);
 - 2.2. Means of connection with a Geographic Information System (GIS)
 - 2.3. Means of support of relational databases (DB) such as MS Access, Oracle, MS SQL Server;
 - 2.4. Graphical User Interface (GUI);
 - 2.5. Generator and editor of the user-defined graphical symbols. It calls Symbol Designer;
 - 2.6. Graphical editor of networks that calls as Topoeditor;
 - 2.7. Generation of the user-defined structures in database. These tables and structures describe network elements such as pipelines, compressor stations, valves, contracts, etc.
 - 2.8. Means of support of spreadsheets;
 - 2.9. Generator of the user-defined reports in form of tables and diagrams;
 - 2.10. Coloring of networks. These means include a generator of the user-defined rules to coloring of nodes and elements in networks;
 - 2.11. Finding paths in networks, etc.
3. Optimization system Graphicord-NPC – the Network Optimizer providing economic and operational optimization of gas networks;
4. System Compressor-Visualizer providing modeling and both economic and operational simulation of compressors and drives that is used in particularly for tabular and graphic representation of optimal set-points and operating points of every machine that Graphicord-NPC finds i.e. of its results.
5. Zgleichungen.dll that is a shared dynamic library of procedures and functions from fluid dynamics, thermodynamics and numeric mathematics, which are used in a lot of applications concerning computations of
 - 5.1. Pipelines;
 - 5.2. Gas networks;
 - 5.3. Compressors;
 - 5.4. Turbines and other drives;
 - 5.5. Equations of state;
 - 5.6. Material and thermodynamic properties of gas and mixture compositions;
 - 5.7. State functions in thermodynamics;
 - 5.8. Tool boxes and such programs as Graphicord-NPC, Compressor-Visualizer, Compressor-Characterizer, etc.

Each of these (sub-) systems and their interactions are described separately below.

The data interface between the system of monitoring and control of DCS / SCADA with our programs such as Graphicord-Gis and Compressor-Visualizer is concentrated in a single software function. Adaptation of this function allows to bind the Network Optimizer to DCS / SCADA and to integrate it there.

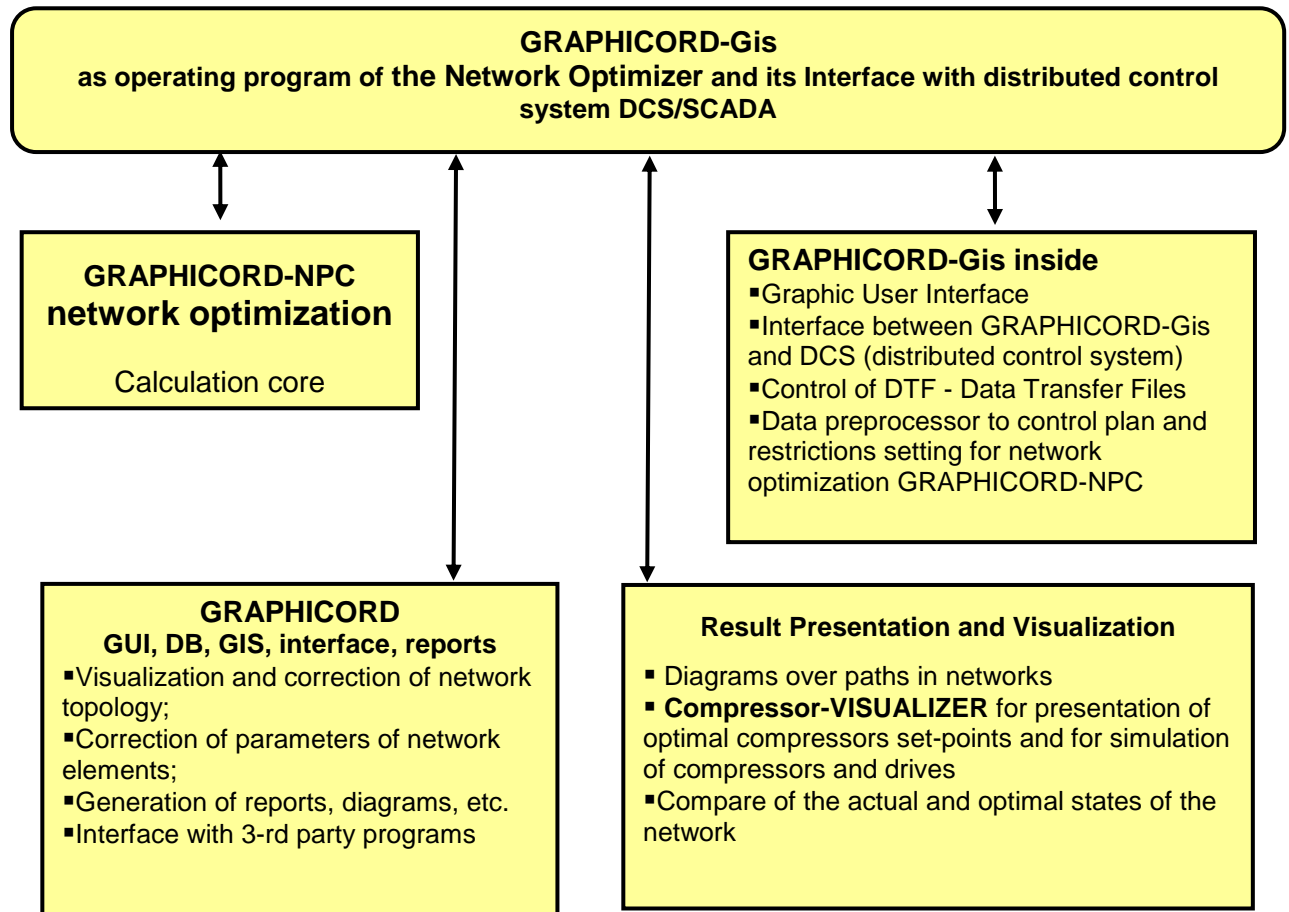


Fig.1. Interaction of sub-system in Graphicord Suite and functions in the operating program Graphicord-Gis

3 Graphicord-Gis as an operating program of the Network Optimizer

s. Fig. 1. Purposes of Graphicord-Gis are as follows:

- (i) Graphicord-Gis combines and consolidate into a unit complex the optimization program Graphicord-NPC; GRAPHICORD that supports graphics and database; Compressor-Visualizer and the other means of representation of results;
- (ii) It Provides data exchange with a distributed control system of gas pipelines, i.e. with DCS / SCADA

3.1 The basic functions of Graphicord-Gis

Graphicord-Gis makes the following:

1. Reading data of measurements and contract restraints from a distributed control system DCS/SCADA. For this purposes, it is used e.g. an Excel-interface.
2. Data preprocessor to control and generate the gas network, technological and commercial restraints, and control plan of actions
 - 2.1. Generation and preparation of the gas network for calculations

- 2.2. Construction of the technological and commercial restraints for the optimization on the base of data of measurements and contracts that exists and were read
- 2.3. Implementation of a control plan i.e. control commands of the system and of user
3. Start and control of calculations
 - 3.1. A start of the on-line calculations, which are based on current and forecast data from DCS/SCADA
 - 3.2. A start of the off-line calculations, which are based on data that are the results of on-line calculations or that a user gives or corrects manually
 - 3.3. A start of the calculations based on data from an external source or a the third party system
 - 3.4. It provides iterative calculations, if they are useful or necessary after tolerance criteria
4. It saves input and results of the calculations providing the following
 - 4.1. Support of database (DB) of Graphicord for scenarios, networks and the network elements
 - 4.2. Support of database constructed from the text files and directories that represent input, intermediate data and results of calculations
 - 4.3. Synchronization of DB of Graphicord with DB of text files
5. Generation and visualization of results
 - 5.1. Generation of tables and diagrams of parameters distributed along the user selected paths of the network
 - 5.2. Visualization of tables and diagrams of each optimal operating point of compressor stations, compressors and drives, which has been found by the network optimization
 - 5.3. Providing the opportunity to view the results as text files or as tables in Excel
 - 5.4. Results analysis: A comparison between the current and optimal states of the network and its tabular and graphical visualization of in the form of
 - 5.4.1. Tables in Excel spreadsheets and
 - 5.4.2. A topological diagram of the network with parameters
 - 5.5. It visualizes a table with report about violations of constraints as a result of the calculations
 - 5.6. It constructs a log-file of errors during reading data of measurements and contracts from DCS
6. A built-in emulator of DCS / SCADA providing a demo of on-line operation of Graphicord-Gis
7. Management of settings of programs
 - 7.1. General settings of the program:
 - 7.1.1. Paths and directories;
 - 7.1.2. Notation language for directories;
 - 7.1.3. Selection of the human language of communication between the user and the program;
 - 7.1.4. The options of use:
 - 7.1.4.1. Off-line;
 - 7.1.4.2. On-line with a real DCS / SCADA;
 - 7.1.4.3. On-line with an emulator of DCS / SCADA that provides a demo-version;
 - 7.2. Data selection for the calculations:
 - 7.2.1. Assignment of date and hour for the calculations, i.e. time that lies in the future for the planning or in the past for the analysis, for which the network state must be calculated and optimized;
 - 7.2.2. The choice of initial state from DCS / SCADA;
 - 7.3. Some parameters of calculations such as maximal number of iterations, tolerances and accuracies, boundary values of feasibility, etc.
 - 7.4. Options of the result visualization such as options for construction of tables and diagrams of parameters distributed along the networks

- 7.5. Assignment of a selected operating point to the role of a graphical topological template of the network "Actual scenario / Actual topology" for subsequent calculations and for saving their results in the database GRAPHICORD.

Graphical implementation of some basic functions of the operating program Graphicord-GIS is shown in Fig. 2 - 7.

3.2 Components

The components of the operating program Graphicord-GIS and their basic functions are shown in the next Table 1.

Table 1. The components of the operating program Graphicord-GIS and their basic functions

Module	Functions
GraphicordGis.exe	Operating program of the system Graphicord–Suite.
GamosDataReading	Data reading of measurements and contract restraints from a distributed control system DCS/SCADA. For this purposes, e.g. an Excel-interface is used.
GamosData	Implementation of a control plan i.e. control commands of the system and user.
	Preparation of input data for implementation of calculations concerning the network optimization
Ortsk, Ortskurven	Construction of tables and diagrams of optimal flow, pressure and the required power in the gas network.
	Generation of tables and diagrams of parameters distributed along the user selected paths of the network
KenF_Vis	Visualization of tables and diagrams of each optimal operating point of compressor stations, compressors and drives, which has been found by the network optimization
RES_COMPARE	A comparison between the current and optimal states of the network and a tabular and graphical visualization of the comparison.

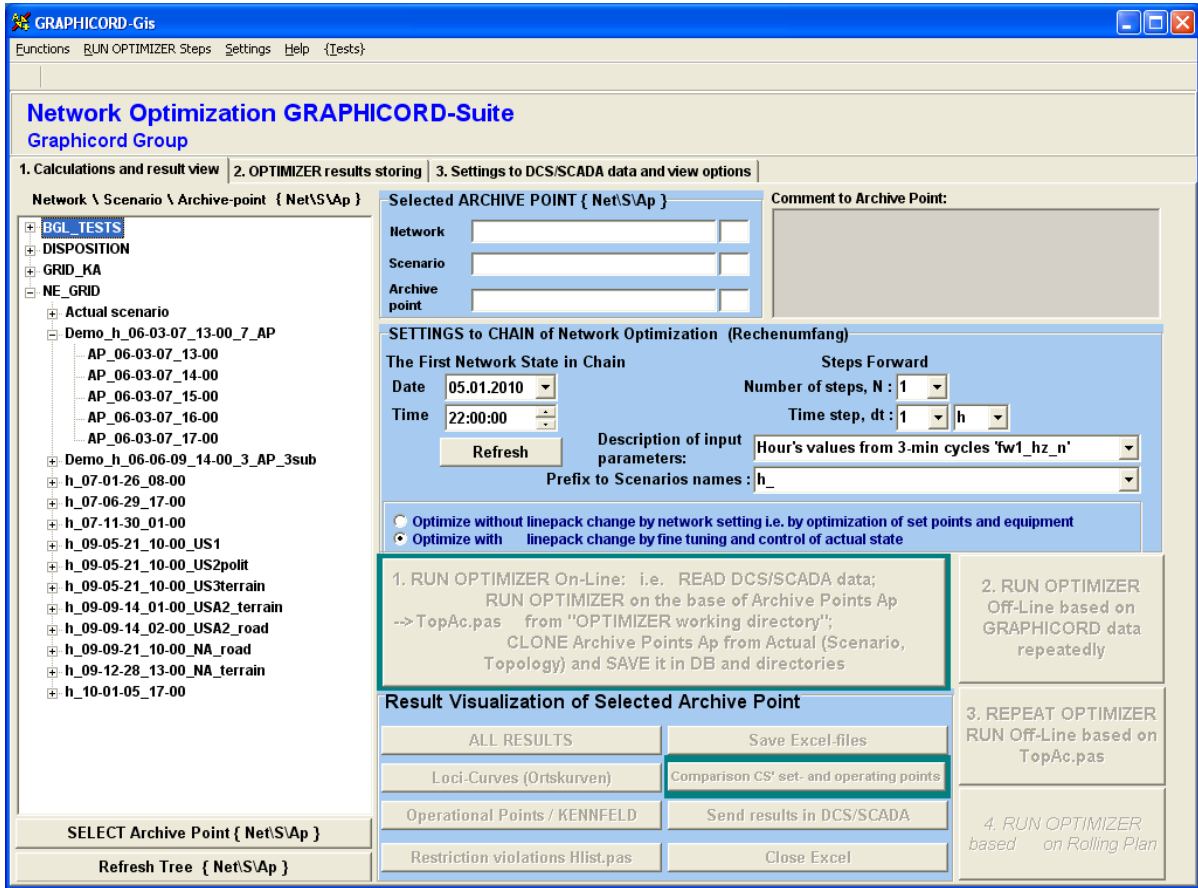


Fig. 2. Graphical implementation of the following function of the operating program Graphicord-GIS: Option of calculations and display of the results: Selection of (i) a scenario of the calculations; (ii) An initial state of the gas network, and (iii) a base time for the data reading e.g. from a customer forecast

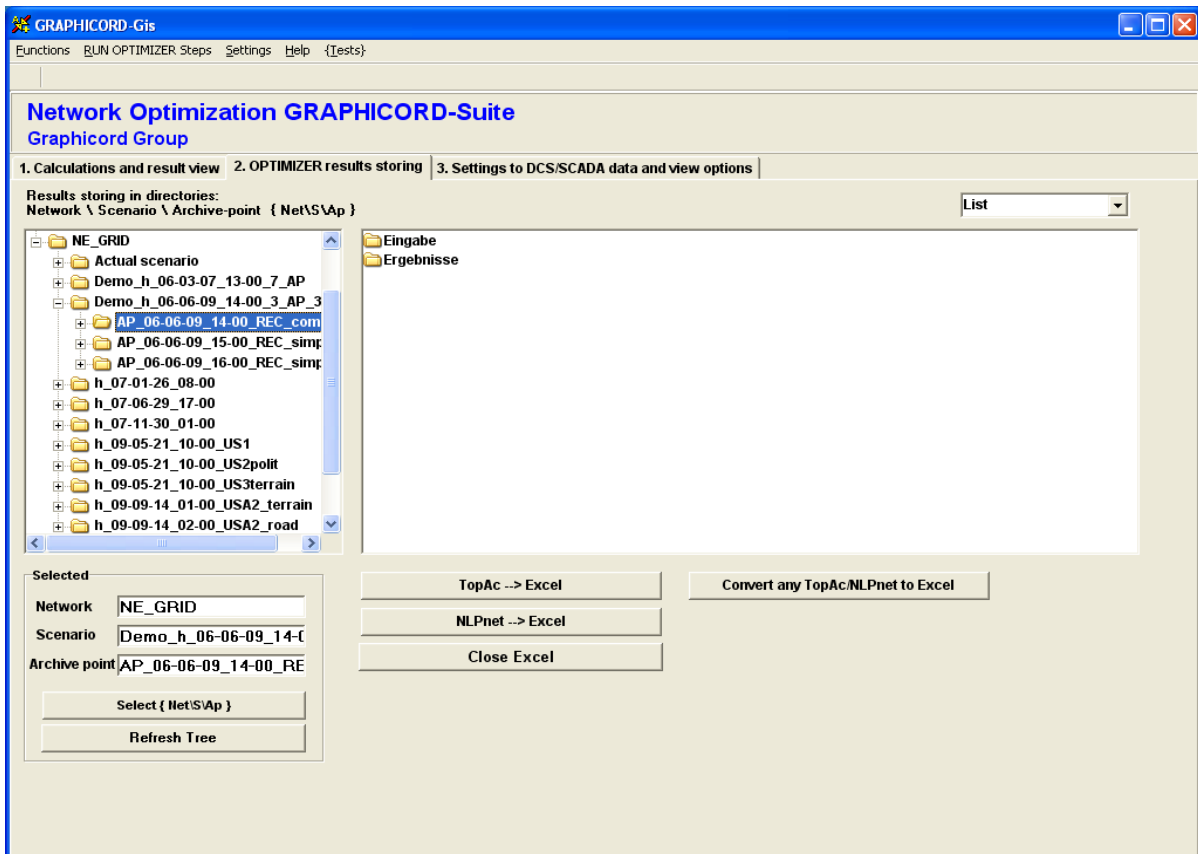


Fig. 3. Graphical implementation of the following function of the operating program Graphicord-GIS: Selection of files with input and results data for displaying

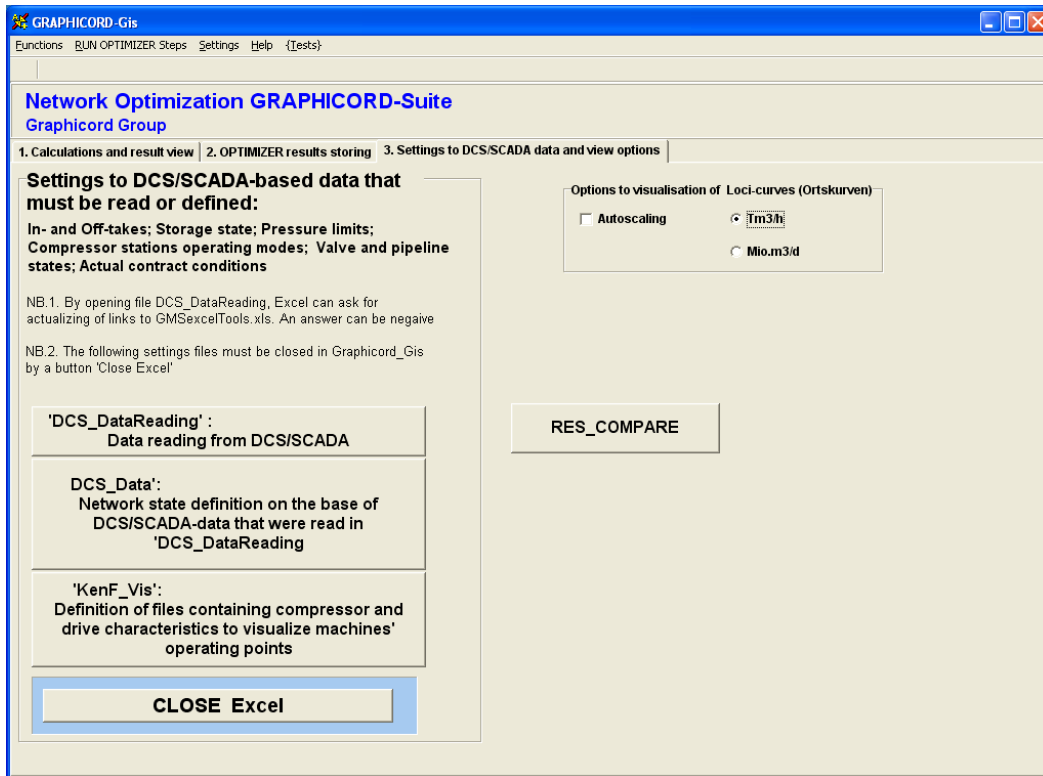


Fig. 4. Graphical implementation of the following function of the operating program Graphicord-GIS: Settings for interface between Graphicord-GIS with DCS/SCADA

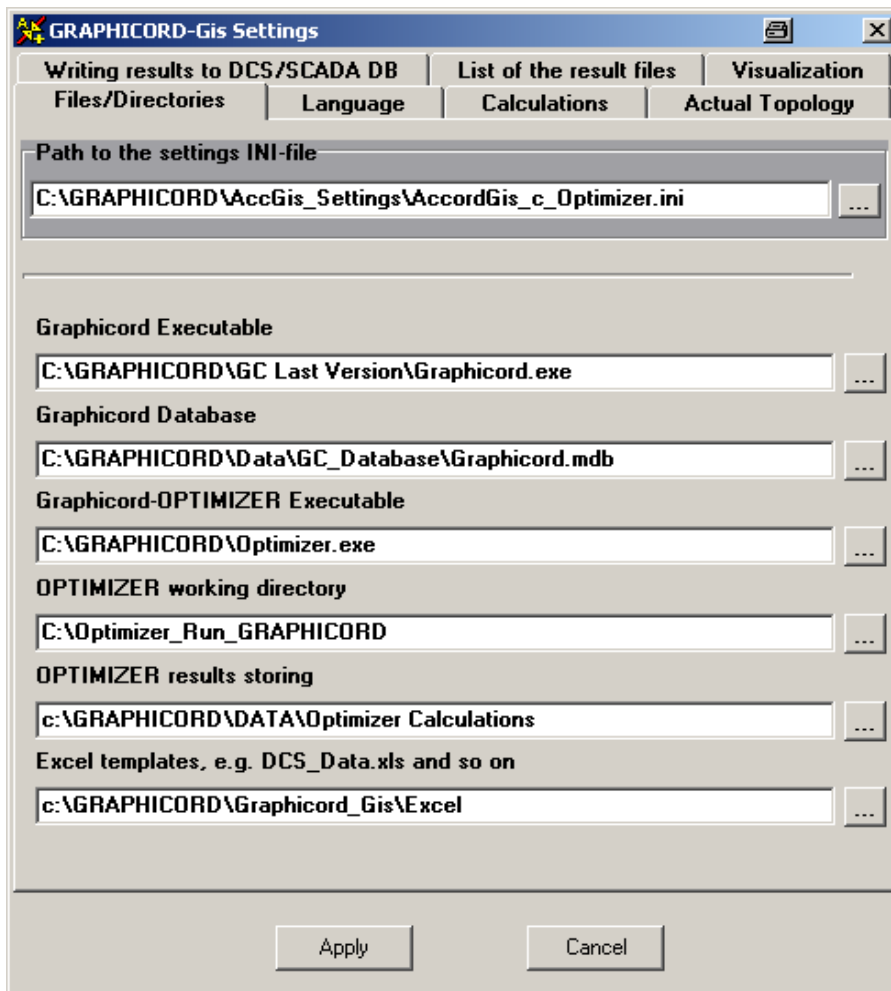


Fig. 5. Graphical implementation of the following function of the operating program Graphicord-GIS: Setting for paths to the basic directories and files

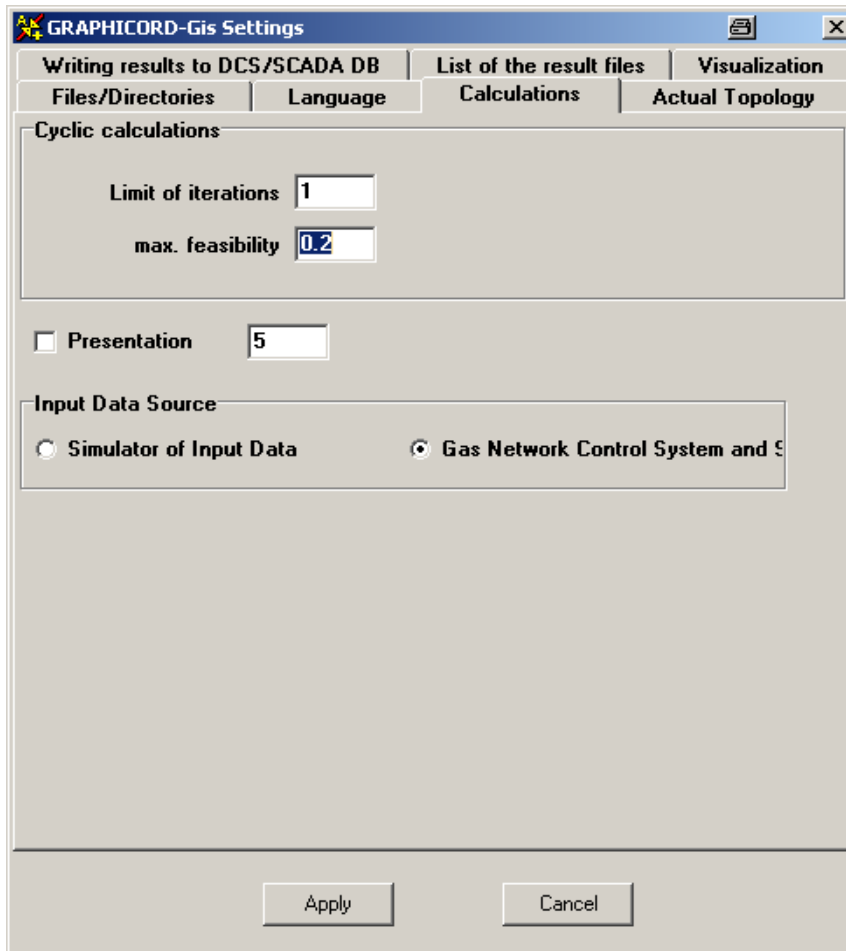


Fig. 6. Graphical implementation of the following function of the operating program Graphicord-GIS: Settings for (i) Some parameters for cyclic calculations; (ii) On-line option: A selection of implementation either a real DCS/SCADA or a built-in emulator of DCS for a demo-version

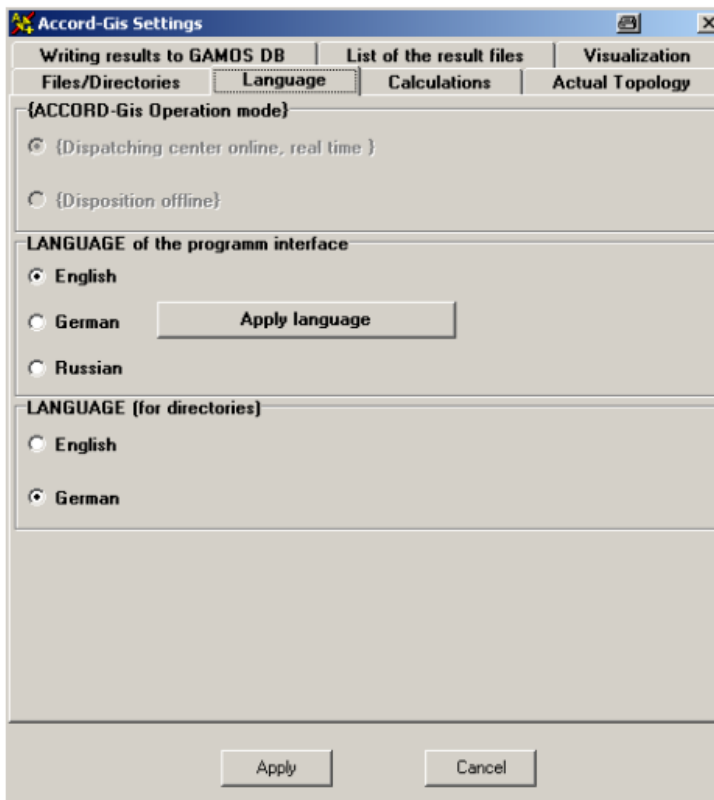


Fig. 7. Graphical implementation of the following function of the operating program Graphicord-GIS: Selection of the human language of communication between the user and the program

4 Graphicord

4.1 Overview

Graphicord is a powerful customizable gas pipeline network modeling, simulation and optimization tool. The key features of Graphicord include:

- 1) Integration with Geographic Information System GIS (MS GIS MapPoint) and with maps as bmp-files
- 2) Feature-rich network topology editor
- 3) Archiving and support of versions, scenarios and states of networks
- 4) Symbol and network element editor providing intuitive clear entry of data and graphical symbols
- 5) User defined graphical net-element representation
- 6) User defined versionable element properties
- 7) Automation support for integration with third party systems
- 8) Customizable integration with built-in and third party computational modules
- 9) User defined data import/export format
- 10) Support of spreadsheet format
- 11) Transparent, customizable integration with Excel for charts and graphs presentation (Reports)
- 12) User defined rule-based net-element coloring

For references, a correspondence between the points above and the following Sections is shown in Table 1.

Table 1. A correspondence between the key features of Graphicord and the Sections

No	The key features of Graphicord	Section
1	Integration with Geographic Information System GIS (MS GIS MapPoint) and with maps as bmp-files	GIS
2	Feature-rich network topology editor	Topoeditor
3	Archiving and support of versions, scenarios and states of networks	Organization of versions, scenarios and states of networks
4	Symbol and network element editor providing intuitive clear entry of data and graphical symbols	Symbol Designer and section Net-Element Editor
5	User defined graphical net-element representation	“ “
6	User defined versionable element properties	“ “
7	Automation support for integration with third party systems	Integration with external applications and section Flexible user definable export and import
8	Customizable integration with built-in and third party computational modules	“ “
9	User defined data import/export format	“ “
10	Support of spreadsheet format	Support of embedded spreadsheet format
11	Transparent, customizable integration with Excel for charts and graphs presentation	Reports putting by Generator of tables and diagrams

	(Reports)	
12	User defined rule-based net-element coloring	Graphical Format Rules

4.2 Symbol Designer

The Symbol Designer helps to create and save symbol objects for use in Graphicord. With the Symbol Designer, a user can define the visual characteristics of a symbol and determine where other symbols can connect to it. Once the user finishes designing a symbol, he/she can save it to disk for later use. This method enables users to create a library of symbol objects for use by Graphicord. All symbols that appear in Fig. 1 are constructed by Symbol Designer by users.

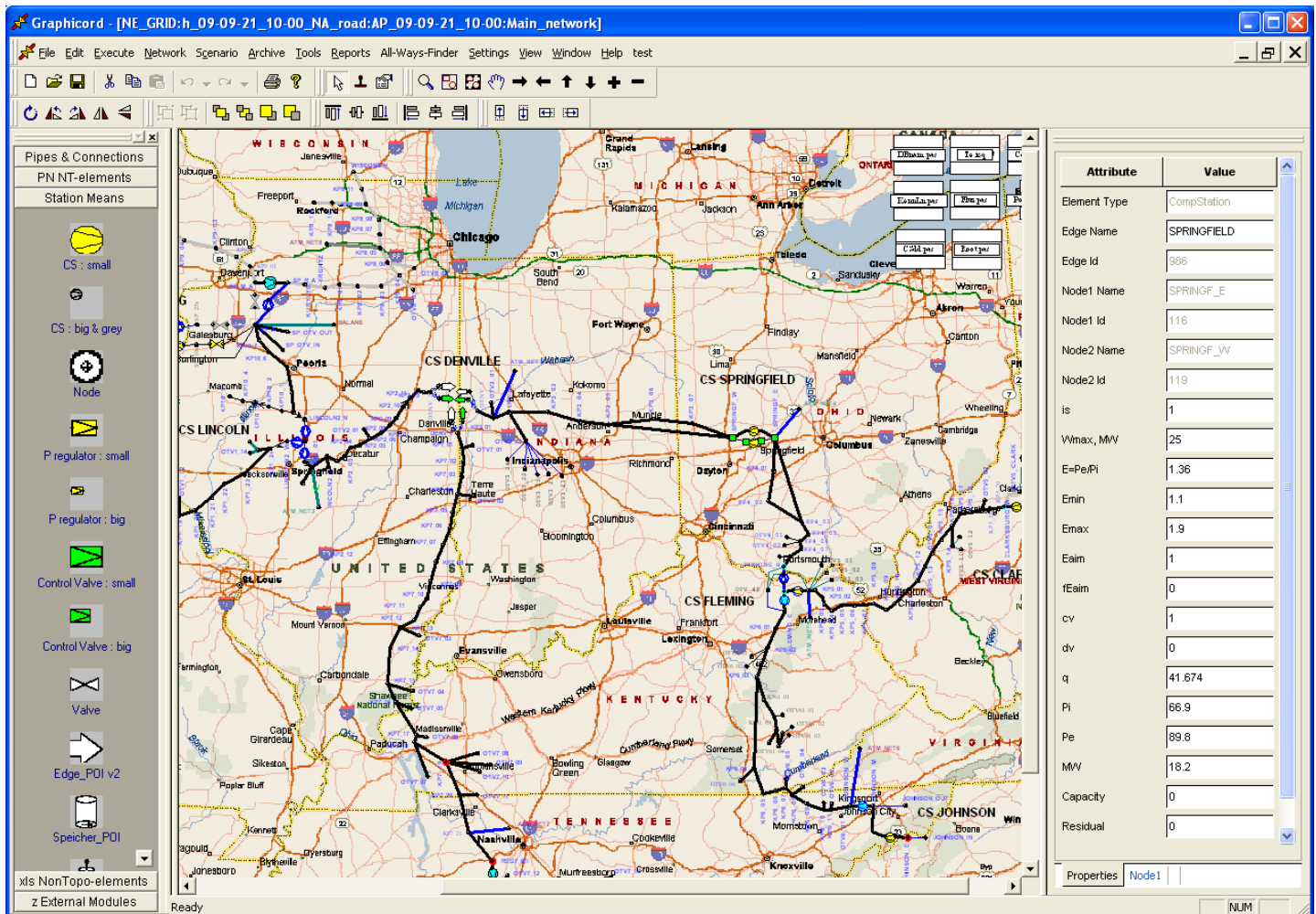


Fig. 1. Graphical symbols appearing in the network diagram in the central window and in the left pane that contains net-element libraries with available net-elements.

4.3 Net-Element Editor

Net-Element Editor allows creation and modification of basic network elements: nodes, edges, and non-topological elements. Using Net-Element Editor, a user can define new elements or extend and modify existing ones. Each Net-element is defined with a graphical symbol and a collection of properties. From the definition of element properties, a database table schema is derived, allowing subsequent storage of element instances in the database. Net-elements are grouped into Net-element libraries that are later used by the Topoeditor, s. Fig. 2

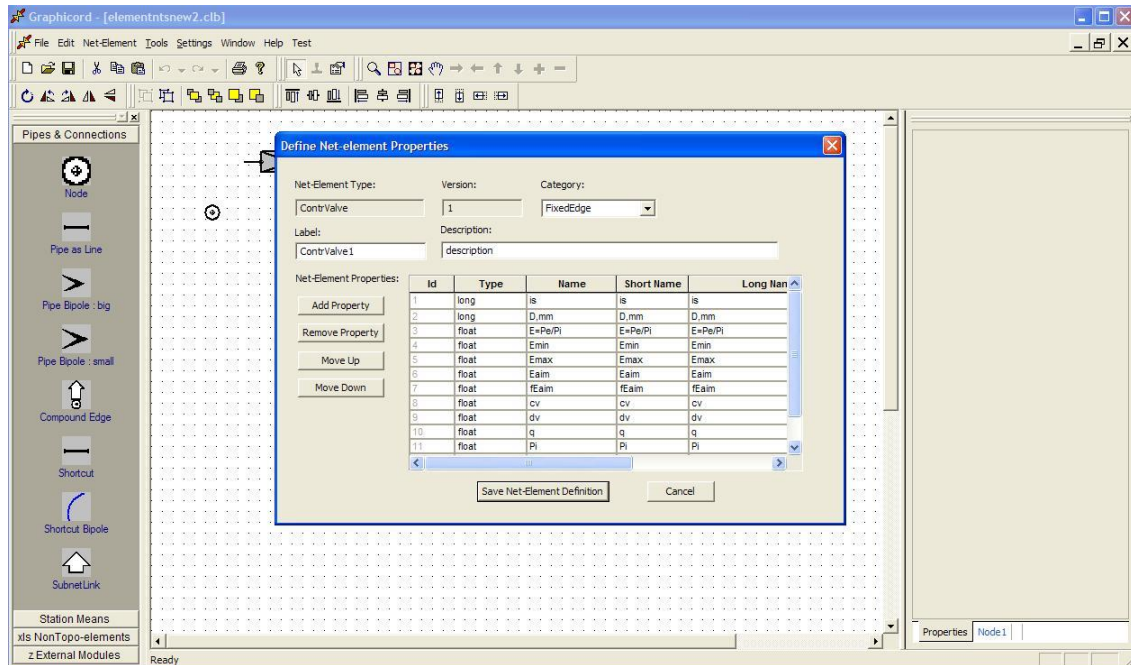


Fig. 2. Editing and definition of Net-element properties

4.4 Topoeditor

Topoeditor is used to create or modify gas pipeline networks. A network consists of one or more subnetworks, each shown in its own window. Topoeditor provides an easy and intuitive WYSIWIG way of creation and editing of subnetworks. The left pane contains net-element libraries with available Net-elements. There are two modes of insertion of Net-elements into the main Topoeditor window: drag-and-drop and select-and-paste. Properties of network elements can be entered using tabular format, by selecting the Element and modifying element properties on the right pane. Each Net-element instance properties are pre-filled with defaults.

The networks designed by Topoeditor are shown in Fig. 1, 3. In Fig. 1, a map from Geographic Information System (GIS) is shown as background, in Fig. 3 no map is used.

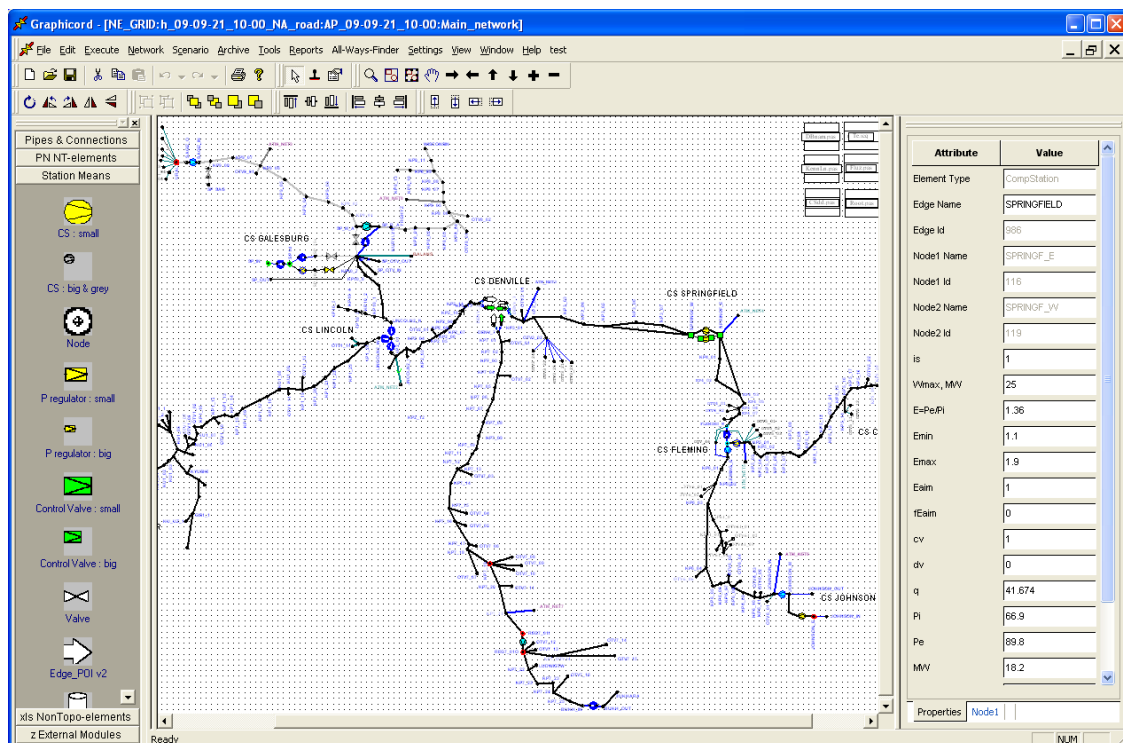


Fig. 3. A subnetwork designed by Topoeditor.

4.5 Organization of versions, scenarios and states of networks

Graphicord provides a hierarchical organization of versions, scenarios and states of networks. The hierarchy consists of 3 levels: Networks, Scenarios, and Archive Points. Each network consists of a set of Scenarios. A Scenario represents a variant state of the network. Scenarios in turn contain a set of Archive Points. Each Archive Point represents a state of a particular network at particular point in time. An Archive Point consists of a set of subnetworks and Scenarios, Archives and Subnetworks can be cloned providing an easy way to perform experiments with network topology and changes of network parameters in time.

Fig. 4 shows an operation of opening a given network. One can see the levels of networks, scenarios, archive points and subnetworks. Fig. 5 shows functions that manage networks. Deleting, cloning, renaming of networks, scenarios, archive points and subnetworks are available there.

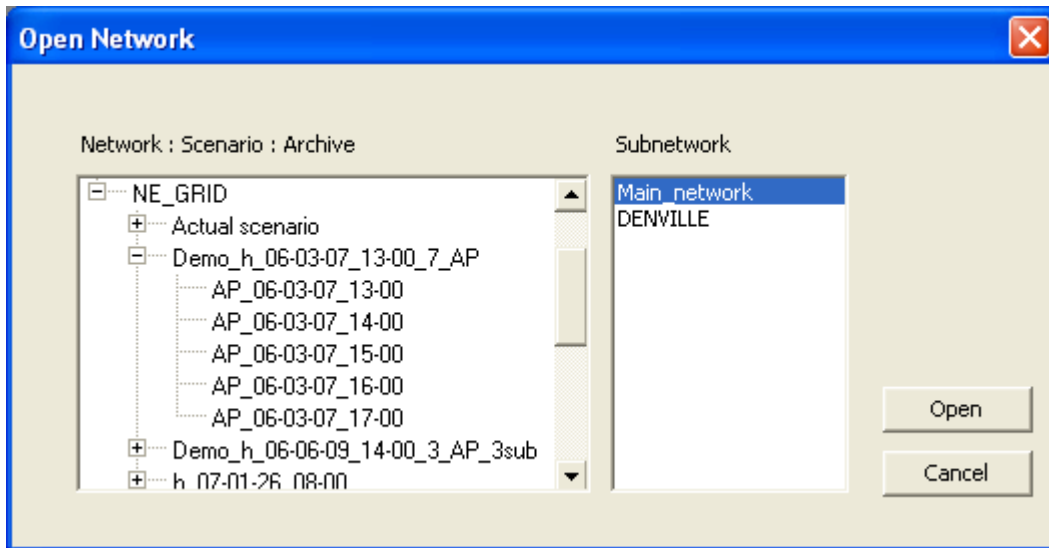


Fig. 4. Opening a given network. Levels of networks, scenarios, archive points and subnetworks are shown.

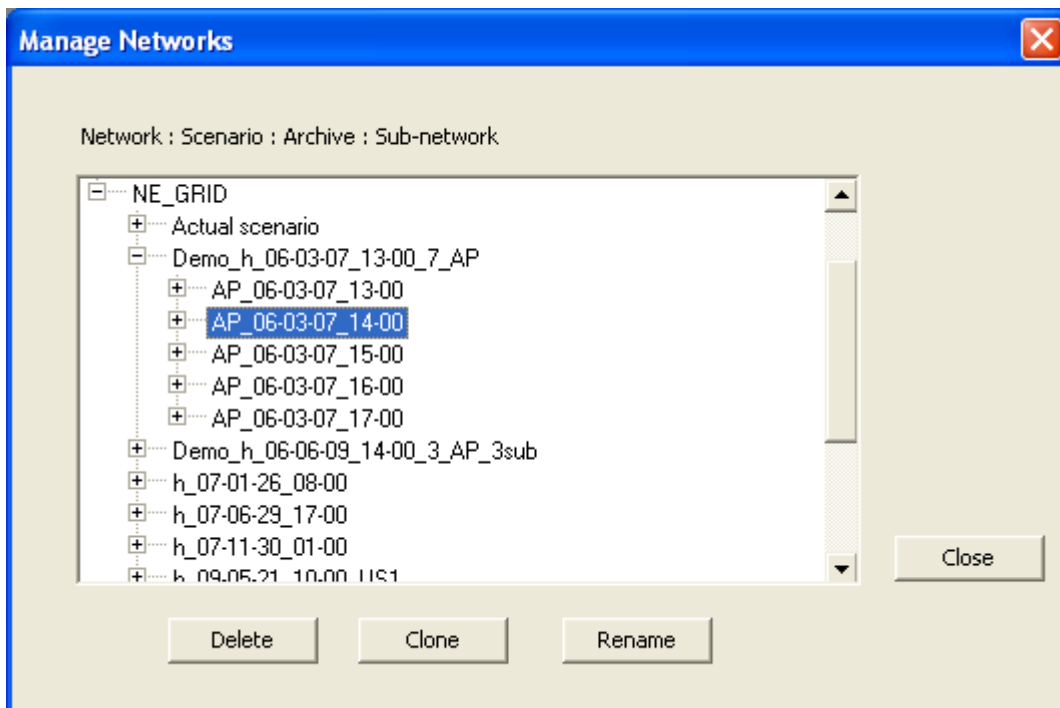


Fig. 5. Functions of the mode "Manage networks". Deleting, cloning, renaming of networks, scenarios, archive points and subnetworks are available there.

4.6 GIS

Graphicord is integrated with MapPoint GIS. The Geographical maps provided by MapPoint are displayed on the background of a network. By request additional GIS systems could be integrated with Graphicord. In Fig. 1, a map from Geographic Information System (GIS) is shown as background for a network.

4.7 Integration with external applications

Rich automation interface of Graphicord provides essential integration features. Most Graphicord functions and features are exposed and can be invoked from an external application. Transparent database structure allows direct data-level integration. VB Script can be generated by and executed within Graphicord allowing tight integration with MS Office applications.

On the other hand, the 3-rd party exe-modules and applications can be added to be called from Graphicord, s. Fig. 6. There are available both manual and programming call of the 3-rd party applications from the Graphicord environment.

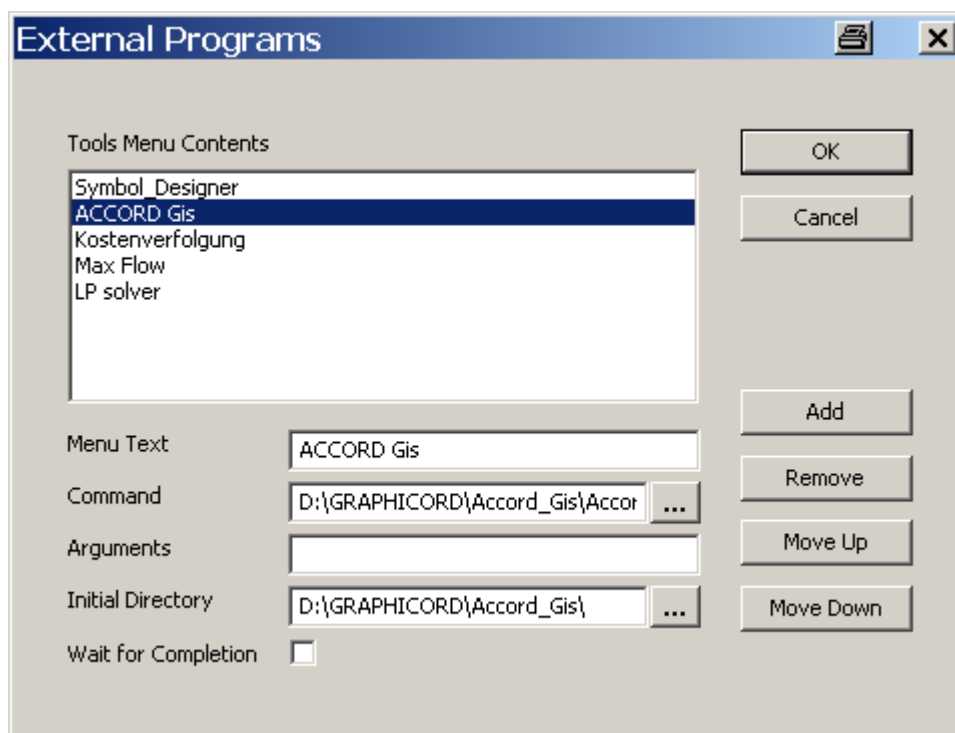


Fig. 6. Adding external programs as the 3-rd party applications to Graphicord

4.8 Path Finder

Graphicord provides a simple interface for finding paths on the networks based on specified criteria. Found paths can be iteratively displayed by highlighting the set of elements from which the path is composed.

Fig. 7 shows how conditions for Path Finder can be set.

Fig. 8 displays results of Path Finder as available paths between 2 nodes in case if less equipment is available on the compressor station.

Fig. 9 displays results of Path Finder as available paths between the same 2 nodes as in Fig. 8 but in different case, if more equipment is available.

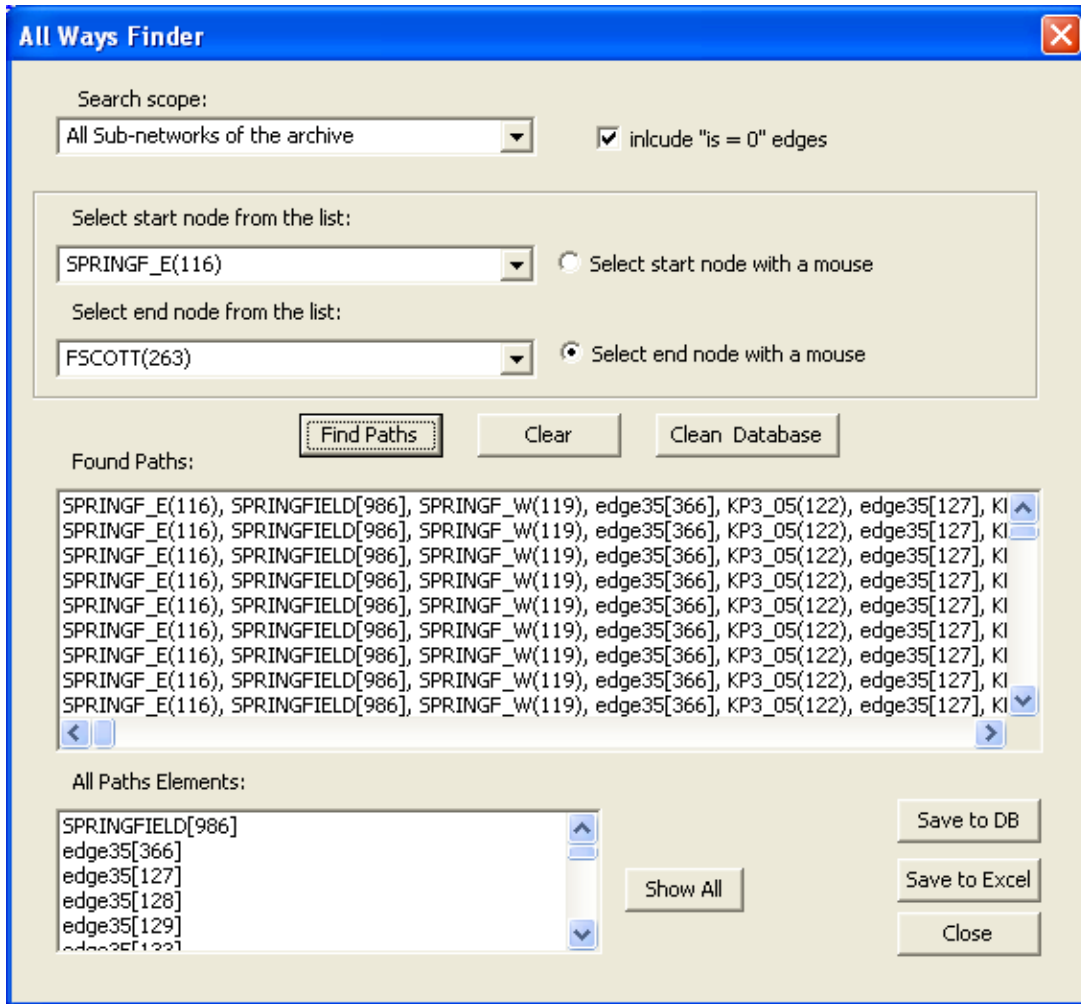


Fig. 7. Setting conditions for Path Finder

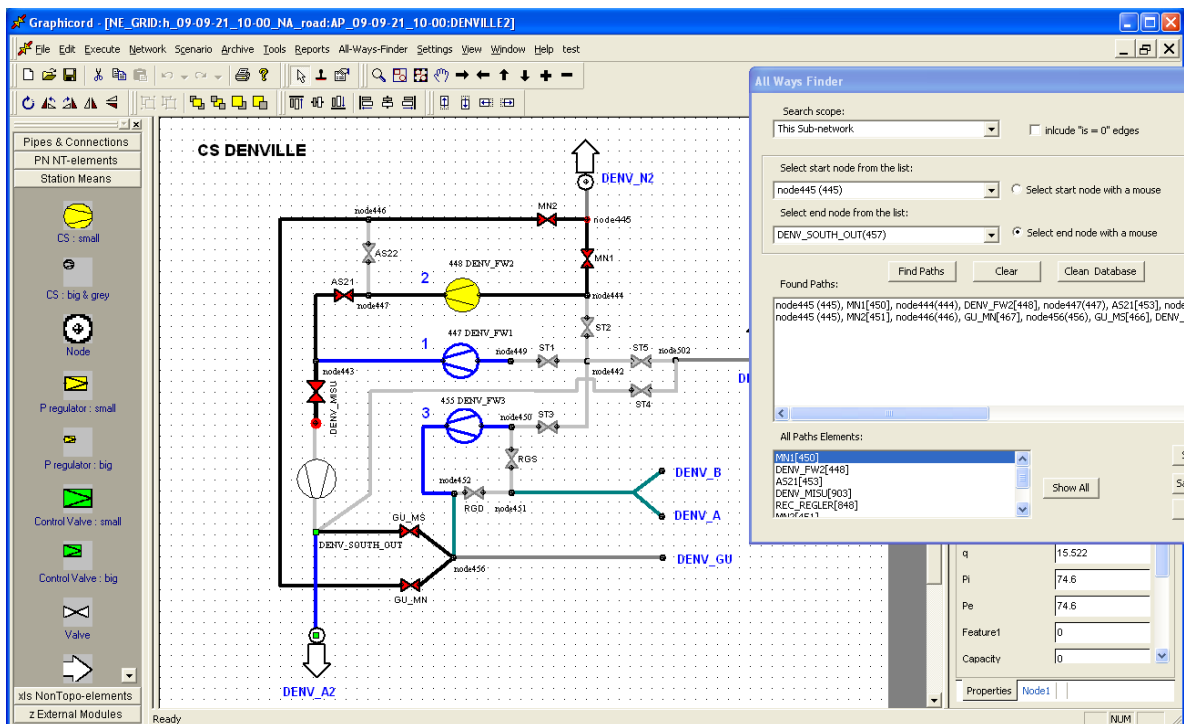


Fig. 8. Results of Path Finder in case if less equipment is available

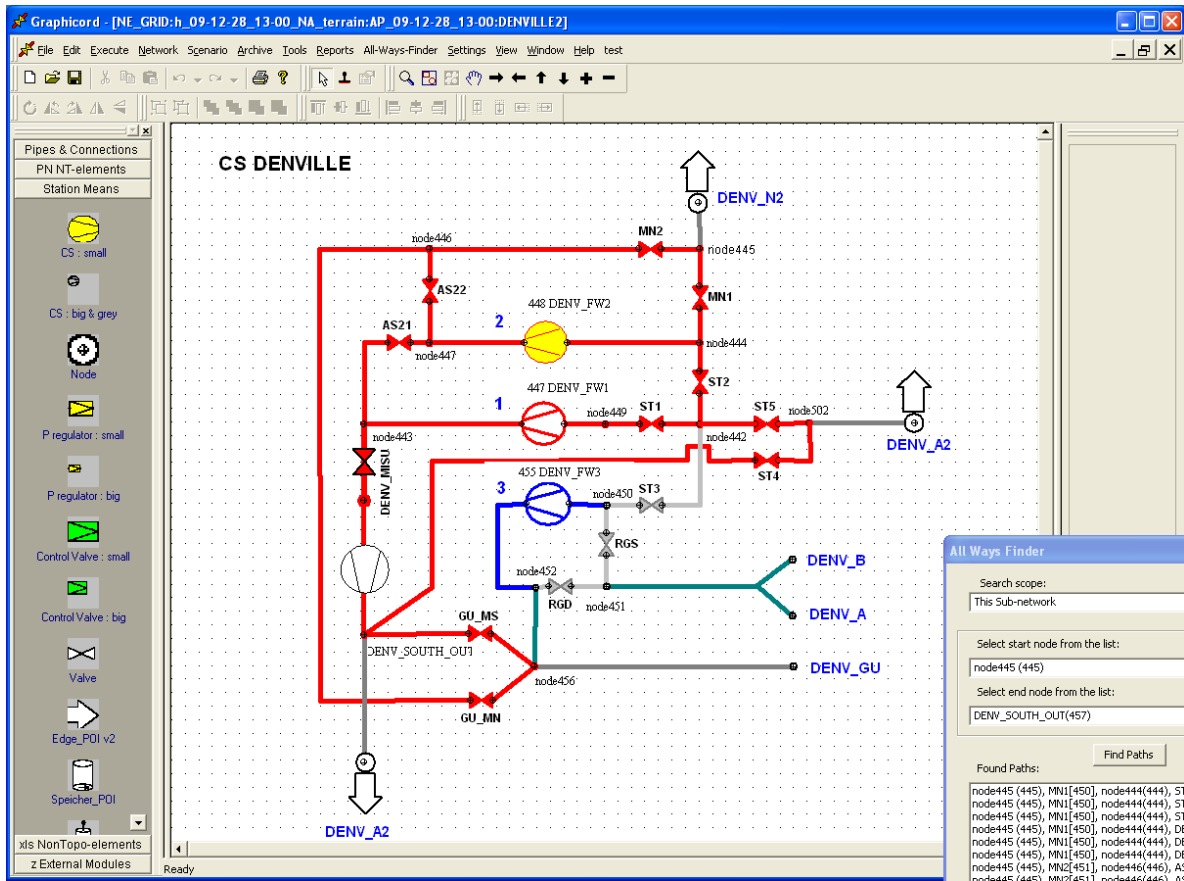


Fig. 9. Results of Path Finder in case if more equipment is available

4.9 Support of embedded spreadsheet format

Graphicord supports spreadsheet format in particularly for tabular processing of input, plain and Excel files, s. Fig. 10.

Row	Offtake	Node_v	Node_name	Sign	Q(V)
1	1.Offtake_DZHEZKAZG	300	DZHEZKAZG	-1	5
7		360	INC9_01	1	0.23
8		359	INC9_02	1	0.88
9		363	INC9_04	1	0.64
10		460	BAVK_B	1	1.93
11		403	CHNAZ_IN	1	1.12
14	2.Offtake_Saksaul_SW	204	Saksaul_SW	-1	1
17		360	INC9_01	1	0.05
18		359	INC9_02	1	0.4
19		363	INC9_04	1	0.17
20		460	BAVK_B	1	0.39
23	3.Offtake_BROIC_A	354	BROIC_A	-1	1.5
26		360	INC9_01	1	0.08
27		359	INC9_02	1	0.2
28		363	INC9_04	1	0.26
29		460	BAVK_B	1	0.64
30		403	CHNAZ_IN	1	0.3
33	4.Offtake_OTVS_11	364	OTVS_11	-1	16
36		360	INC9_01	1	0.73
37		359	INC9_02	1	2
38		363	INC9_04	1	2.68
39		460	BAVK_B	1	6.18
40		403	CHNAZ_IN	1	4.4

Fig. 10. Example of tabular processing of input file in spreadsheet format in Graphicord

4.10 Reports putting by Generator of tables and diagrams

Graphicord integrates transparently with Excel. Graphs and charts can be defined through a user-friendly interface, creating complex queries. VBA script that executes the query is generated then and creates complex tables, graphs and charts at the run time in Excel. The results can be saved to use again.

Fig. 11 shows how queries, tables and diagrams can be define to generate them in Graphicord as reports in Excel. Fig. 12 shows the simple example of generated tables and diagrams.

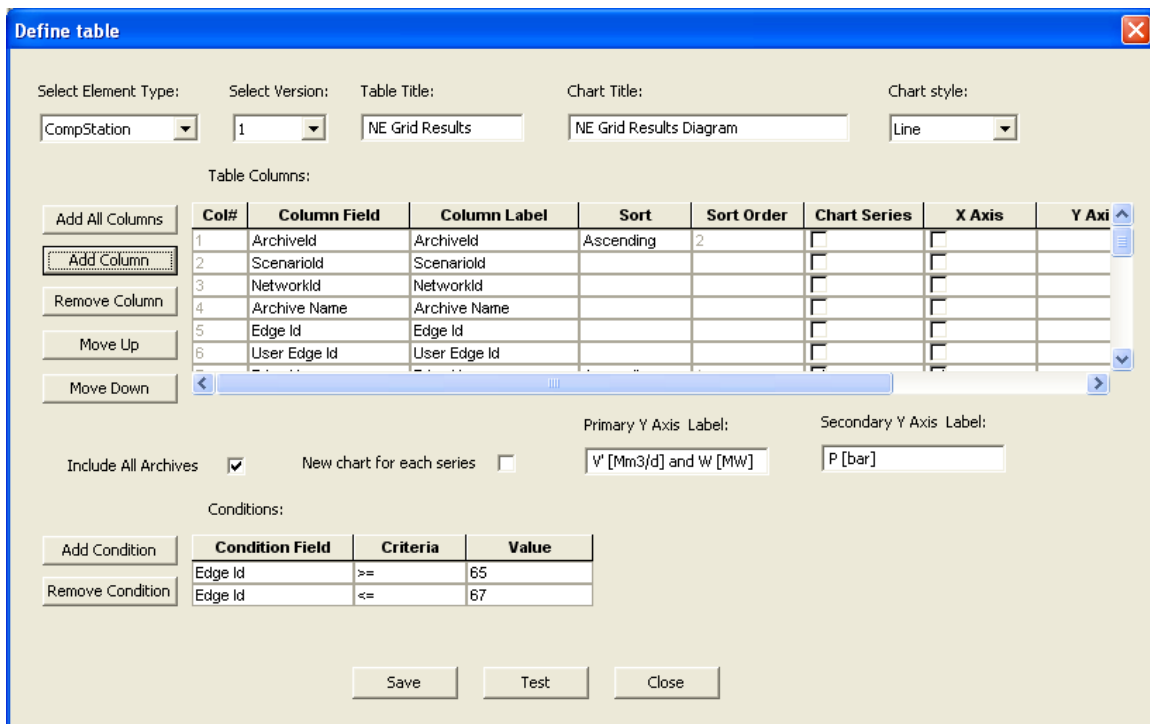
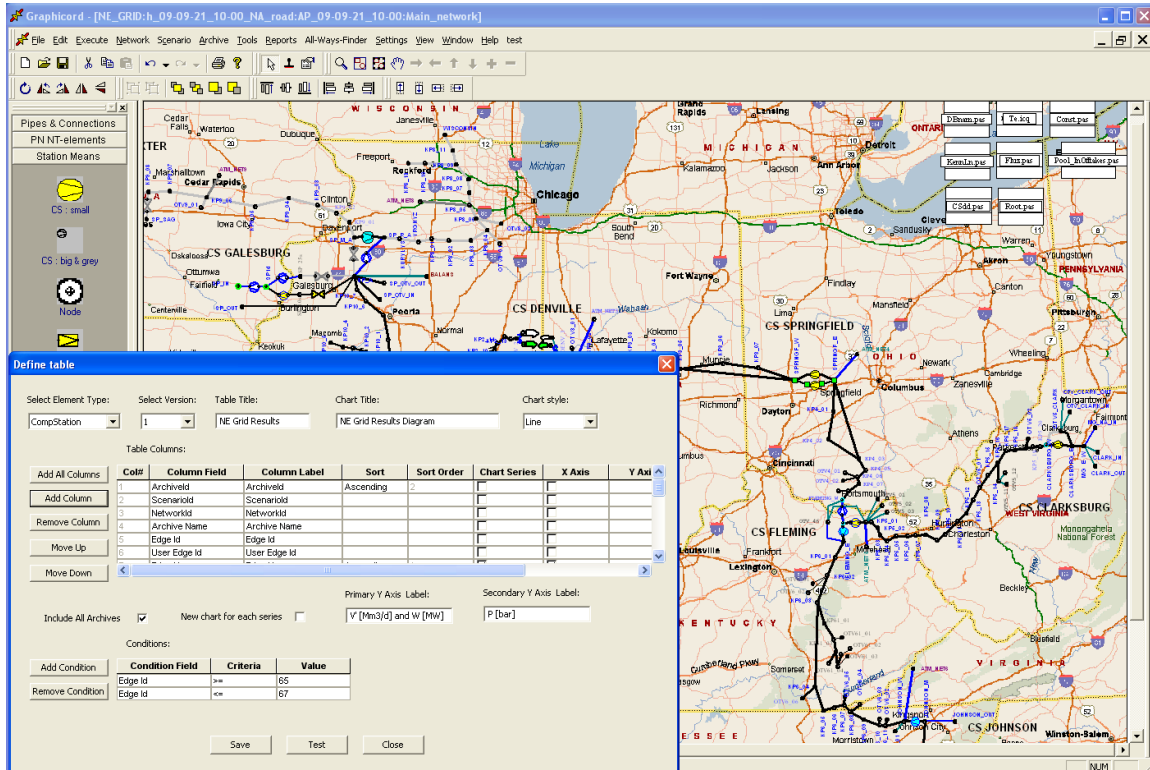


Fig. 11. Definition of query, table and diagram to generate them in Graphicord as report

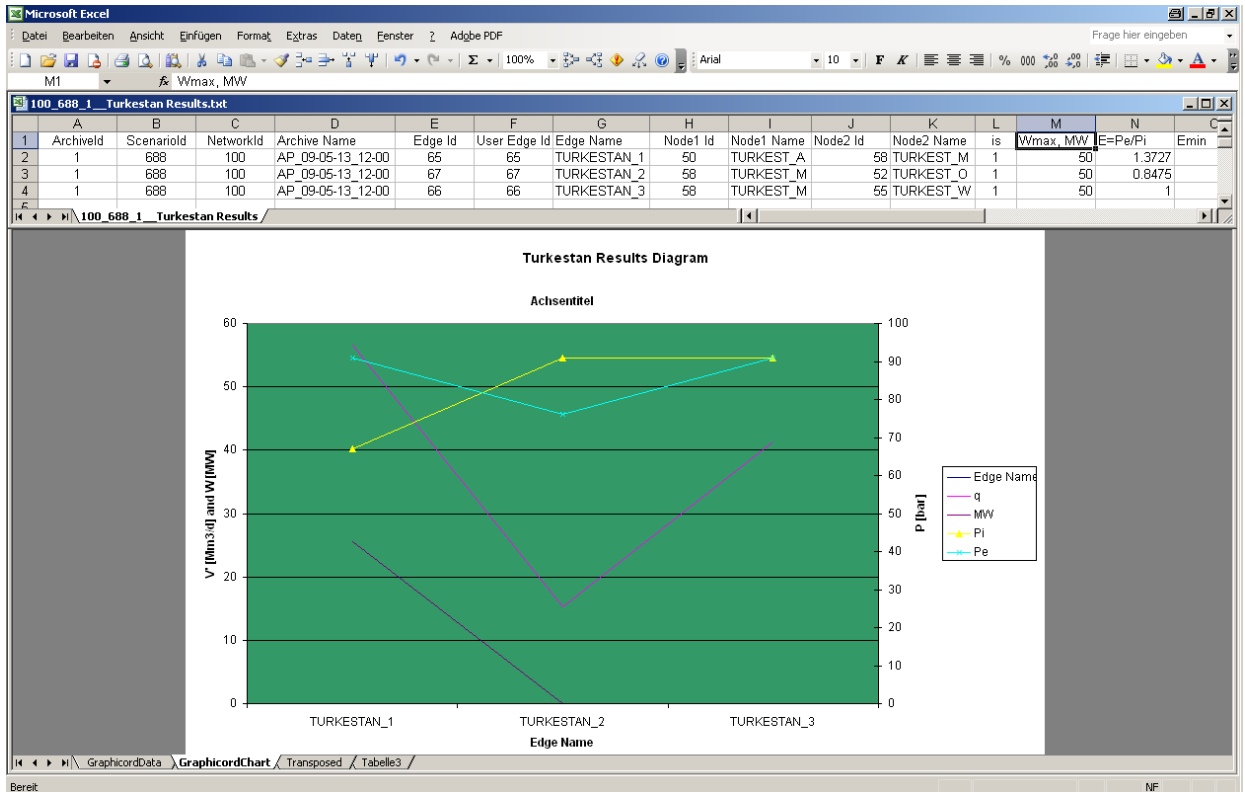


Fig. 12. Simple example of generated tables and diagrams.

4.11 Graphical Format Rules

One of the important visualization features of Graphicord is a graphical format rules. A user can define conditional visual formatting of net-elements. Graphical properties that can be conditionally modified include net-element fill color, line color, line width and element rotational orientation.

By request the rules can be applied and visual representation of the network will be modified based on the conditional rules and properties of particular net-elements belonging to the network.

Fig. 13 shows how Net-Element Graphics Rules can be defined. Fig. 14 shows results of user defined Net-Element Graphics Rules as coloring nodes and network elements depending on their properties.

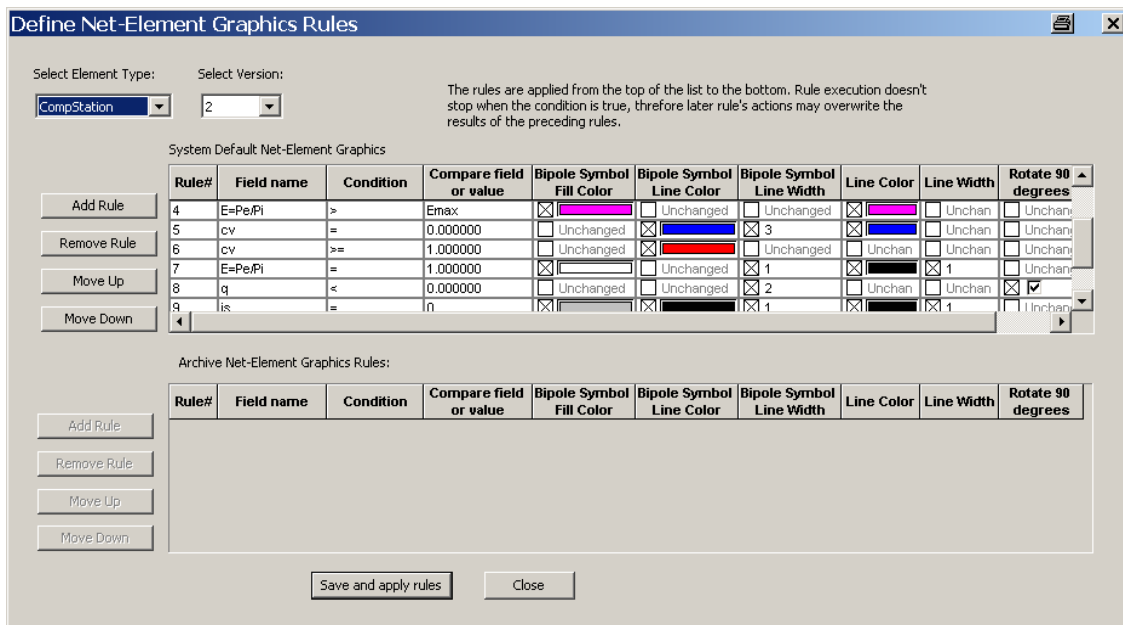


Fig. 13. Definition of Net-Element Graphics Rules

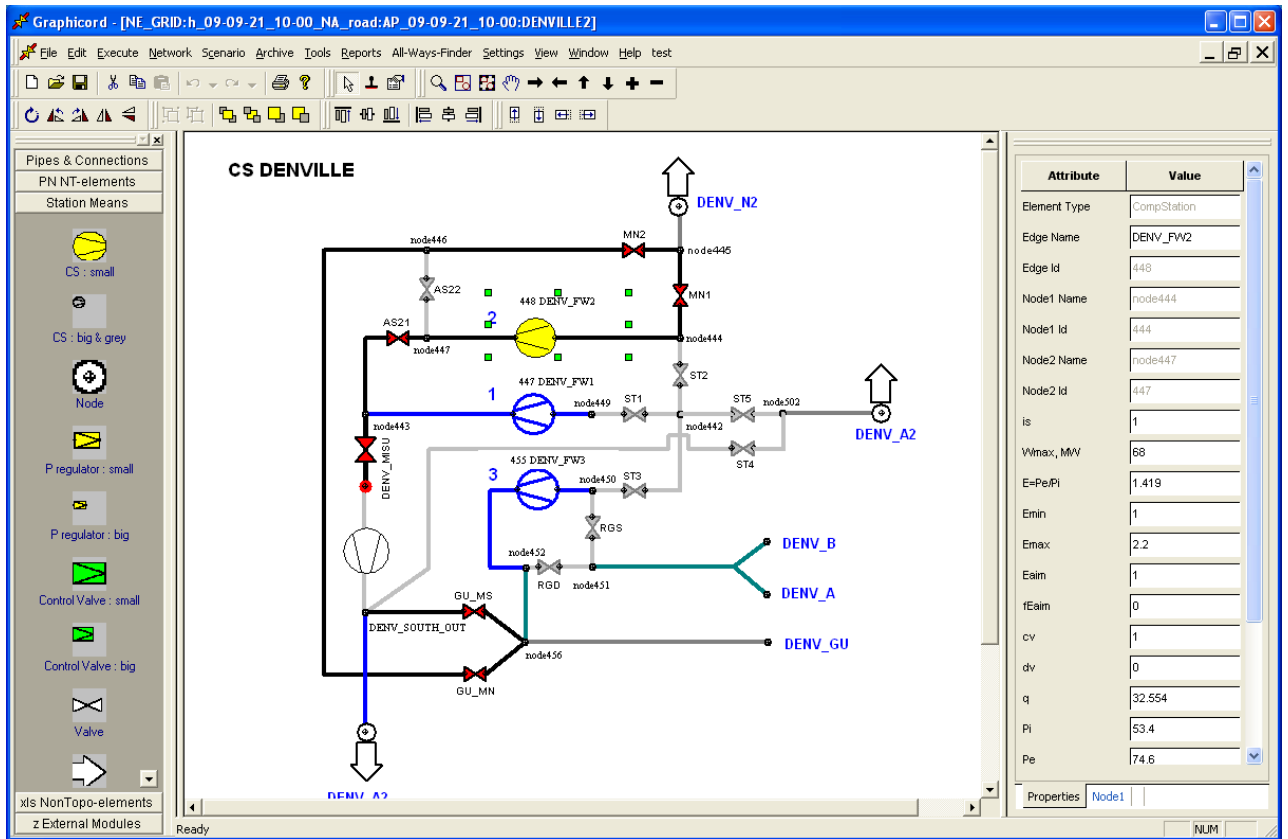


Fig. 14. Coloring nodes and network elements as result of user defined Net-Element Graphics Rules

4.12 Flexible user definable export and import

Graphicord allows a user to define a custom export data formats of data transfer files using an interface to the 3-rd party applications. At run-time, data is extracted from the database and a data transfer file created according to selected format. As a third party application may modify the data or provide calculation results, a user-defined format is used to import the data from a user file back into Graphicord database.

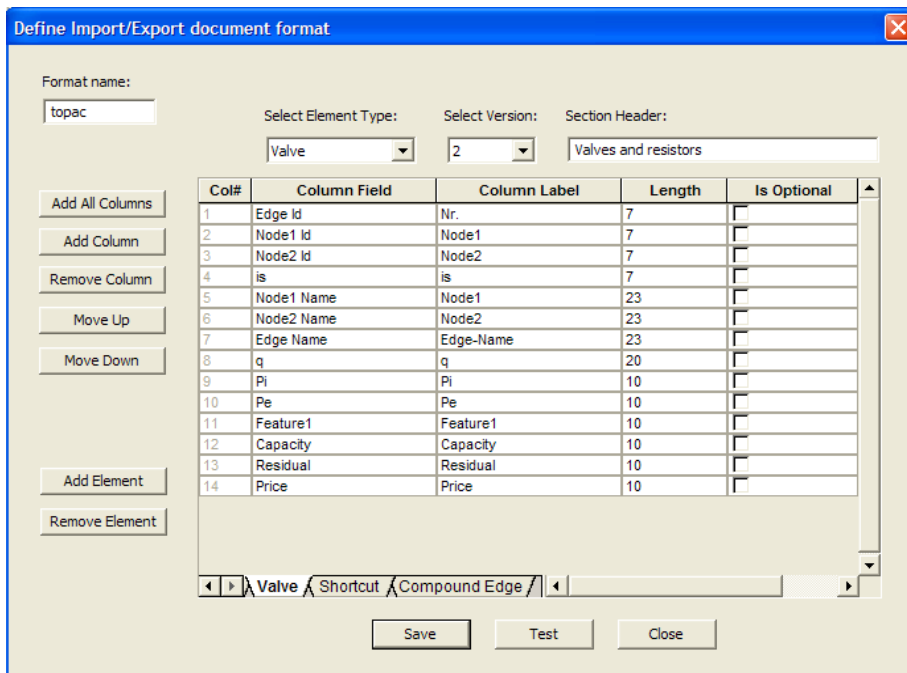


Fig. 15. Definition of data formats of data transfer files.

4.13 System Configuration

Graphicord is suitable for scaling. In the simplest configuration, the system can operate on a usual computer under operating system MS Windows with MS Office installed. More powerful and high-performance configuration consists of the interface or interaction between Graphicord running on a computer under MS Windows with a database server running such a database as either Oracle or MS SQL Server.

4.14 Benefits

- Graphicord is flexible, highly customizable, yet feature-rich program
- Can help determine an optimal parameters for a new network as well as operational parameters for an existing one
- Provides an easy integration with external programs and legacy systems
- Runs on Windows 2000, XP, Vista with MS Office
- Can use MS Access, MS SQL Server or Oracle as a database engine

5 Compressor-Visualizer

5.1 Use

The Compressor-Visualizer is a collective name of programs and files belonging to a family of tools that provide performance monitoring and simulation of operating points of compressors and drives.

The Compressor-Visualizer is used for compressors and its drives for:

- 1) Technological and economic simulation of their operating points
- 2) Simulation of operating points of parallel compressors of the same type
- 3) Performance Monitoring in its simple form.

There are two modes of the use of the Compressor-Visualizer: the off-line and on-line modes.

The standalone off-line mode performs a technological and economic simulation of operating points with data presented tabular and graphically. Charts visualize and present the operating points, operating lines, characteristics and the characteristics diagrams of compressors and drives. During the simulation, it is used thermodynamics, mechanics, and characteristics of the machine as well as prices of energy and fuel.

The on-line mode performs at first the automatic data reading from the control system. Then the data input is coupled with simulation so that the technological and economic simulation of the given operating point is made.

The measured, calculated and simulated values are compared and deviation is shown. So the functions of the performance monitoring are provided.

The sequence of data that were read, simulated and calculated can be saved and presented tabular and graphically.

At each time it is possible to jump from off-line to on-line mode and vice versa.

All functions of the off-line standalone mode are available in on-line mode as well.

5.2 Some terms

A machine is a coupling of a drive and a process compressor.

Under a compressor is to be understood either the process compressor or the entire machine depending on context.

A drive could be a gas turbine, an electric engine, a steam turbine, a piston machine, and so on.

A type of machine T_m is a combination of a compressor T_c and of a drive T_d : $T_m = (T_c, T_d)$.

A station-specific type of machine consists of a type of machine and the characteristics of a station such as the geodetic height of the station etc.

Pressure ratio is a ratio of output pressure to input pressure.

5.3 Interfaces

Simulation and performance monitoring of each type of machine uses Excel interfaces for tabular and graphical presentation. An Excel file corresponds to each type of machine.

The station-specific machine types and the specific compressor machines are listed in the file `DB_Verdichtersimulation_VISUALIZER_Leitsystem.xls` in the worksheet `FileName-Compressor`.

The connection to the distributed control system (DCS) is made by a listing of the addresses in the DCS/SCADA data base. In case of DCS/SCADA GAMOS, these addresses are called info-points. Info-points are listed in the file `DB_Verdichtersimulation_VISUALIZER_Leitsystem.xls` in the worksheet `Info-points`.

5.4 Functions and benefits of Compressor-Visualizer

5.4.1 The main functions

For compressors and drives, we developed the detailed and complete models and uniform models of characteristics that provide the following functions:

- Monitoring of performance, efficiency and parameters of machines on-line
- Technological and economic modeling and simulation of their operating points on-line and off-line
- Visualization of their characteristics and operating points.

5.4.2 Monitoring

To monitor the operating conditions and performance, Compressor-Visualizer uses and provides presentation of

- The machine characteristics,
- The operating points
- Such parameters as gas temperature, gas pressure, gas flow, gas speed, compressor speed, air temperature, exhaust gas temperature, power output, available power, the consumed fuel gas, the consumed electricity, efficiency, etc.

5.4.3 Modeling and simulation of operating points of compressors and drives

Compressor-Visualizer provides economic and operational simulation of operating points of compressors and drives. As result, it provides a tabular and graphical visualization of their characteristics and operating points.

Compressor-Visualizer is used in two options:

- (i) On-Line with a real data from DCS / SCADA;
- (ii) Off-Line with data taken from a plan, from analysis, optimization, and contracts.

5.4.4 Visualization of results of monitoring and modeling

Compressor-Visualizer provides a tabular and graphical presentation and visualization of characteristics, operating points and economic and operating parameters of compressor and drives. The tables and diagrams are constructed in the spreadsheets of MS Excel.

The following diagrams are presented:

- 1) A dependence of pressure ratio on the flow volume of the transported gas **$P_{out}/P_{in} = f(Q)$**
- 2) A dependence of the available power on the flow volume **$W = f(Q)$**
- 3) A dependence of the output gas temperature on the flow volume **$T_{out} = f(Q)$**
- 4) A dependence of the output gas pressure on the suction flow volume **$P_{out} = f(V_n)$**
- 5) A dependence of pressure ratio on the suction flow volume **$P_{out}/P_{in} = f(V_n)$**
- 6) A dependence of the adiabatic head on the suction flow volume **$H_{ad} = f(V_n)$**
- 7) A dependence of the compressor efficiency on the flow volume **$E_c = f(Q)$**
- 8) A dependence of the available power on the compressor speed **$W = f(N_c)$** by different turbine efficiency **$E_t = \text{Const.}$**

5.4.5 Benefits

Compressor-Visualizer is used for the following.

- Monitoring of performance, efficiency and parameters of machines
- Maintenance planning
- Planning operation of the gas networks and compressor stations
- Contract planning

- Optimal load sharing in a compressor station
- Steady state optimization of operation of gas networks
- Design of gas networks.

For these purposes, Compressor-Visualizer is used either stand-alone or inside the other systems such as

- The Station Profit Creator for Optimal load sharing in a compressor station
- The Network Profit Creator for Steady state optimization of gas networks.

6 The Optimization system

The Optimization system called NPC or Graphicord-NPC is an optimization system that provides the economic and operational simulation and optimization of steady states of general gas networks. All network topologies, and in principle almost all objective functions, are available. Graphicord-NPC is used for design; operation; control; stability analysis; risk analysis; gas market analysis; for determination and booking of energy consumption and CO₂ pollution. The next topics provided are:

- ✓ Network Optimization based on steady-state simulation of flow, pressure and technological systems
- ✓ Optimization based on Flow in Networks with Capacities
- ✓ Evaluation of parameters on the Paths in Networks
- ✓ Estimations between Entry and Exit Points
- ✓ Investment and Tariff Estimation
- ✓ Simulation of Pipelines, Compressors and Drives
- ✓ Visualization of Characteristics, Operating Points and Set-Points of Compressors and Drives

The compressors can be taken into account both with and without a description of their characteristics (called also operating maps or operating ranges).

Calculation of an operating state of the machine is based on thermodynamics, on the machine characteristics, and on the specially developed models of characteristics. The express-calculations without use of machine characteristics are also provided.

Both a quality tracking and a tracking of deliveries are available. This allows the costs to be tracked and optimum selling prices to be determined.

Graphicord-NPC finds and determines

- ✓ Optimal flow and pressure and, if necessary, in-takes and off-takes in the network;
- ✓ Optimal set-point for each compressor station. The optimality is given from the point view of the entire network;
- ✓ Optimal operating mode of each compressor station, i.e. optimal combination of operating machines on each station. In other words, it is optimal solution among available admissible combinations;
- ✓ Optimal set-point for each operating machine.

Both a quality tracking and a tracking of deliveries are available. This allows the costs to be tracked and optimum selling prices to be determined. The following tracking types are available:

- Tracking composition, thermodynamic properties, and quality parameters of gas;
- Tracking suppliers, i.e. portions of different suppliers in the flow;
- Tracking costs of purchased gas.

This allows the minimum selling prices in every point of the network to be determined.

The mathematical and program core of Graphicord-NPC is called ACCORD. ACCORD is the abbreviation for **A**lgorithmic **C**omplex of **C**onstructive non-linear **O**ptimization with **R**estriction on **D**iscrete-continuous variables.

The problems solved by using ACCORD are related to the area of large-scale, non-linear, discrete-continuous optimization for general networks. The optimization process that has been developed represents a distributed branched multi-level computational process. It is based on non-linear and integral optimization and on graph theory. Its main feature is the obtaining of dominant solutions for network fragments. During optimization, the methods adapt themselves to the specific networks and to the topology of surfaces corresponding to objective function, restrictions, and variables.

ACCORD has both an input interface and an output interface in the form of text files. So, the file transfer protocol (FTP) is used. As a result, ACCORD can be linked to the third party programs; to databases; to distributed control systems DCS/SCADA; to various high-level functions; to gas forecast; to dynamic simulation of gas networks; to a graphics editor; to a GIS - geographical information system to create a network; to obtain initial values of supplies, demands and gas parameters; to generate and present a tabular and graphical output. In particular, it is linked to the programs Graphicord and Graphicord-Gis, which manage and implement all such links and connections.

6.1 Objective functions using in Graphicord-NPC

Subject to specified technical and commercial constraints of the network state, there are available several, in principle almost all industrial and economic objective functions, such as the following.

6.1.1 Operational optimization

1. Minimization of energy consumption consisting of fuel gas and purchase electricity – in costs or power units
2. Maximization of total throughput or flow – maximization of total off-take
3. Determination of a feasible network state, which is the nearest to the given desired state. This is such network state, whose values are the most nearest to the parameters, which have been set for the flow, gas delivery, pressure, compression ratio, as well as for contractual parameters
4. Finding out a feasible network state covering set-points of in-takes, off-takes, pressures, and pressure ratios
5. Determination of optimal injections and withdrawals for all facilities of gas storage in the network; etc.

6.1.2 Economic optimization

1. Profit maximization
2. Minimization of WACOG – weighted average cost of gas
3. Determination of gas deliveries and of the network state that allows the nearest reach to the given desired WACOG

6.2 Variables using in Graphicord-NPC

6.2.1 Discrete (integer) variables

Equipment and equipment schemes to be in operation on the compressor stations.

On every station, it call as operating mode of the station and means an admissible combination of operating machines on the station.

6.2.2 Continuous variables

1. Pressure
2. Pressure ratio on the control valves and compressor stations
3. In-takes and off-takes for supply, demand, and storage
4. Flow

6.3 Data model as entity-relationship model

The data model is presented in the form of a graph of the entity-relationship model (s. Fig. 1). It can be presented in the form of a list of entity types.

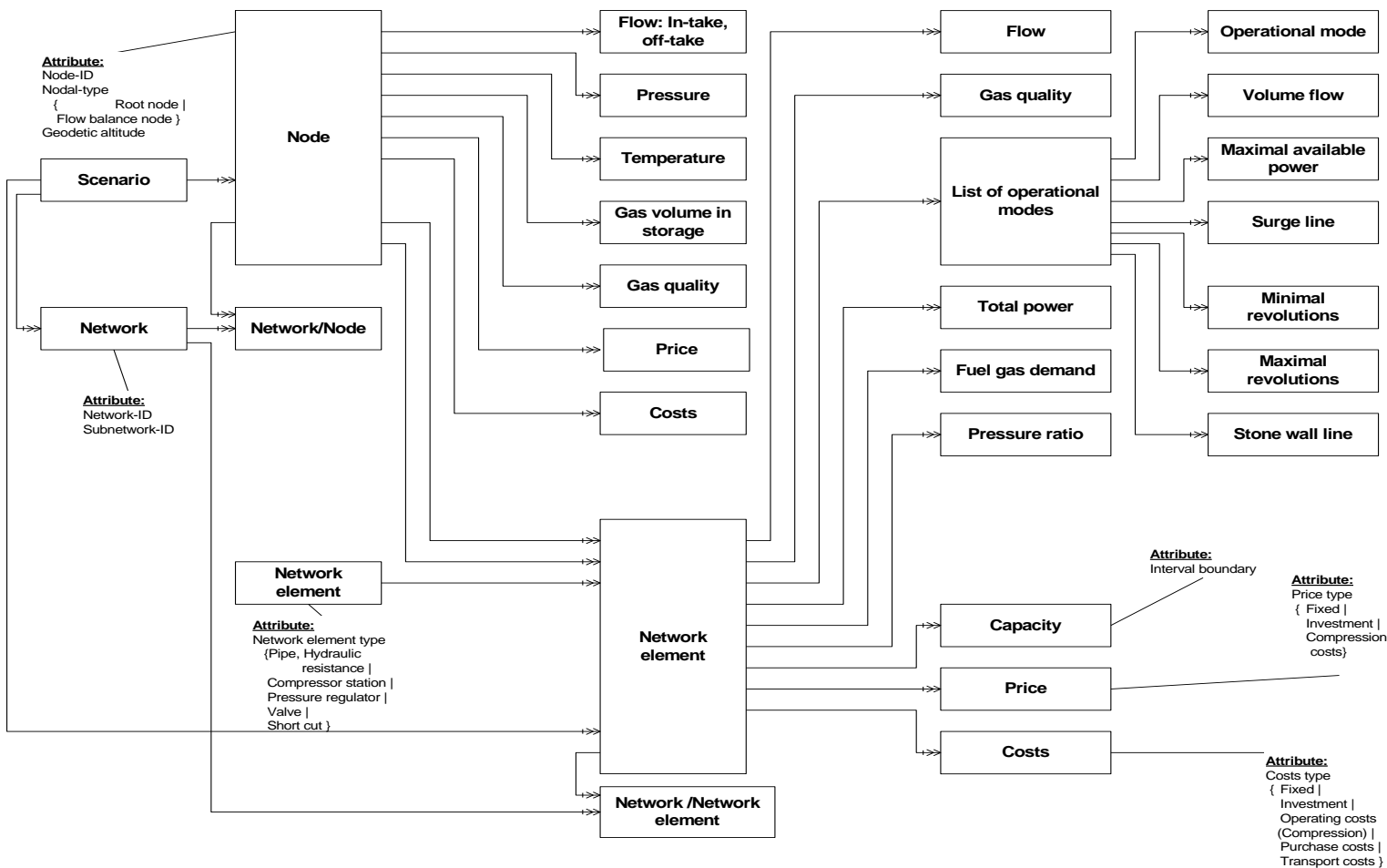


Fig. 1. A graph of the entity-relationship model

6.4 Benefits

1. Optimization System Graphicord-NPC is a flexible highly customizable tool with a wide range of functions
2. Graphicord-NPC allows to determine optimal parameters of new network for investment planning and design; for operation of existing network; for support of contracts and operating agreements
3. Graphicord-NPC determines the optimal load sharing across the network and at each compressor station. Load sharing takes into account the efficiency and developed power of drives and local prices for electricity and fuel gas
4. Thanks to the reliability, speed and quality of results, Graphicord-NPC can be used for the network operation as a control and regulating tool, which generates set-point; minimizes the costs of energy consumption and CO₂-pollution; and provides reliable operation of equipment on gas network and at stations
5. Graphicord-NPC possesses and provides both economic and operational objective functions
6. The economic objective functions can be used in planning the gas transportation to increase revenues, net profit and total profit
7. The economic objective functions that consider the price of purchased gas can be used to determine the amount of gas purchases
8. Operational optimization of the network is one of the bases for constructing the plan of repair and renovation of the equipment