UDC 621.316.1 **doi: 10.20998/2224-0349.2022.02.09**

S. SHEVCHENKO, D. DANYLCHENKO, D. KUZNETSOV, M. Z. QAWAQZEH, O. MIROSHNYK

POSSIBILITIES OF USING PSS®SINCAL, ETAP, POWERFACTORY SOFTWARE FOR MODELLING ELECTRIC POWER NETWORKS

The article is devoted to modeling of electrical networks. The article discusses the positive and negative features of simulation programs. Special attention is paid to the principles of the program. The article discusses such programs as PSS®SINCAL from Siemens; ETAP from Operation Technology and PowerFactory from DIgSILENT GmbH. In the work, we considered the programs and decided that the most successful solution for working with the modeling of the electrical network and the impact of compensating devices on the electrical network would be the use of the PSS®SINCAL software from Siemens. For more than 20 years, the PSS®SINCAL platform has enabled engineers to solve various challenges of variable distribution, transmission and industrial power systems, including maintaining high reliability of supply and efficient integration of distributed energy resources. With PSS®SINCAL's modular platform, power system planning and operation engineers are supported throughout the entire workflow, from raw data import and network modeling (taking into account past, current and future conditions) through basic and advanced calculations to large-scale simulations and analysis protection, as well as other methods in the time and frequency domains. PSS®SINCAL is used in more than 100 countries by transmission and distribution planning engineers, protection engineers, consultants, power plant and industrial grid operators, operations planning engineers, IT specialists, researchers, and more. Thanks to its modular design, PSS®SINCAL is highly flexible and customizable. It offers a wide range of analysis functions for the planning, design and operation of power systems, allowing you to model and study: power quality, frequency stability, distributed generation interconnection, protection coordination, power restoration, economic design solutions and much more.

Keywords: electric network, energy efficiency, voltage, reactive energy, modeling software, PSS®SINCAL, ETAP, PowerFactory, electric energy losses, reactive energy flows.

С. Ю. ШЕВЧЕНКО, Д. О. ДАНИЛЬЧЕНКО, Д. С. КУЗНЄЦОВ, М. З. КАВАКЗЕХ, О. О. МІРОШНИК

МОЖЛИВОСТІ ВИКОРИСТАННЯ ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ PSS®SINCAL, ETAP, POWERFACTORY ДЛЯ МОДЕЛЮВАННЯ ЕЛЕКТРИЧНИХ МЕРЕЖ

Стаття присвячена моделюванню електричних мереж. Розглянуто переваги та недоліки програм моделювання. Особливу увагу приділено принципам роботи програми. Розглянуто такі програми як PSS®SINCAL фірми Siemens, ETAP фірми Operation Technology та PowerFactory фірми DIgSILENT GmbH. В роботі були розглянуті програми і прийнято рішення, що найбільш вдалим рішенням для роботи з моделюванням електричної мережі та впливу компенсаторів на електричну мережу буде використання програмного забезпечення PSS®SINCAL фірми Siemens. Платформа PSS®SINCAL вже більше 20 років дозволяє інженерам вирішувати різні завдання систем розподілу, передачі та експлуатації промислових енергосистем, включаючи підтримку високої надійності електропостачання та ефективну інтеграцію розподілених джерел генерації. За допомогою модульної платформи PSS®SINCAL інженери з планування та експлуатації енергосистем отримують підтримку протягом усього робочого процесу, від імпорту вихідних даних і моделювання мережі (з урахуванням минулих, поточних і майбутніх умов) через базові і розширені розрахунки до великомасштабних симуляцій і захисту аналізу, а також інших методів в часовій і частотній областях. PSS®SINCAL використовується в більш ніж 100 країнах світу інженерами з планування передачі та розподілу електроенергії, інженерами з захисту, консультантами, операторами електростанцій та промислових мереж, інженерами з планування операцій, IT-фахівцями, дослідниками тощо. Завдяки своїй модульній конструкції PSS®SINCAL має високу гнучкість і можливість налаштування. Він пропонує широкий спектр функцій аналізу для планування, проектування та експлуатації енергосистем, дозволяючи моделювати і досліджувати: якість електроенергії, стабільність частоти, взаємозв'язок розподіленої генерації, координацію захисту, відновлення потужності, економічні проектні рішення і багато іншого.

Ключові слова: електрична мережа, енергоефективність, напруга, реактивна енергія, програмне забезпечення для моделювання, PSS®SINCAL, ETAP, PowerFactory, втрати електроенергії, перетоки реактивної енергії.

Introduction. Energy systems are changing radically, and these changes are rapid. The importance of individual sources of electricity and methods of its generation is changing, the methods of its transmission and distribution are changing. Electricity generation is becoming more decentralized, making it increasingly difficult to manage the grid. The world's electricity consumption continues to grow [1-3].

Software discussed in this article allows you to simulate the operation of the power grid and is an invaluable tool for analysis. Due to their high-precision modeling ability, many colleges and universities use this type of software to train power professionals as well as electronic engineering programs [4-6].

To study the electrical network by voltage level, reactive power flows and electricity losses in the electrical network, it is possible to use software to model the modes of operation of the network, but with the following set of requirements [7]:

- availability of functional (modules, etc.) optimization of energy networks by compensating reactive power at different voltage levels;
- step-by-step calculation of the established regimes, before and after the introduction of compensation means;
- the ability to analyze the power supply circuit and suggest ways to optimize reactive power compensation;
- own base of compensating devices with real cost of equipment, for further technical and economic calculations.

Purpose of the article. Energy systems are fundamentally changing, and these changes are rapid. The importance of individual sources of electricity and methods of its generation is changing, and the methods of its transmission and distribution are changing. Electricity production is becoming more decentralized, making it increasingly difficult to manage the grid. Electricity consumption in the world continues to grow steadily.

The software developed in this article allows you to simulate the operation of the energy network and is an invaluable analysis tool. Because of its highly accurate modeling ability, many colleges and universities use this type of software to teach electrical engineering majors as well as electronic engineering programs.

PSS®SINCAL. PSS®SINCAL is software from the German company Siemens.

This software allows you to independently or simultaneously analyze the impact of low, medium and high voltage networks with each other [8].

For more than 50 years, Siemens has continued to improve PSS®SINCAL in close collaboration with product users. The program includes a set of analytical modules and tools that allow you to solve problems: development; design; operation; research of energy systems.

PSS®SINCAL can calculate networks of any voltage class – from low to ultra-high, as well as symmetrical and asymmetrical network models.

From calculation of mode and short circuits to modeling of electromagnetic transients - basic calculation modules, the work of which is the basis of PSS®SINCAL. The basic modules of this software include: calculation of the established mode; calculation of short-circuit currents; harmonics; stability of the system; electromagnetic transients.

Here is an example of using the module of the installed mode.

The calculation of the balance of power, currents and voltages in the network allows you to solve various problems in the planning, design and operational management of electrical networks, namely: planning of new sections of networks, as well as analysis and optimization of existing networks; determination of voltage in all nodes for symmetric and asymmetric networks; determining compliance with regulatory requirements for the allowable minimum and maximum voltage; determining the load of equipment; checking and planning network switches; optimization of settings of adjustable equipment (for example, the position of on-load tap-changers/PBV transformers); comprehensive analysis of transmission and distribution networks; analysis of technical losses.

The set mode calculation module in PSS®SINCAL offers the user fast and efficient methods for calculating the set mode in electrical networks taking into account the high accuracy of modeling for regulated and non-regulated network elements:

- effective methods (e.g. Newton-Rafson, current iteration) to calculate the distribution of currents, voltages and power in symmetric and asymmetric three-phase systems (as well as in 4-wire systems);
- modeling of controlled elements with the help of regulators, such as transformers, capacitors and reactors, or control of individual network elements depending on different variables (e.g. voltage, current, power) throughout the network model;
- support for modeling of complex loads, user-defined models, phase shifts and asymmetric transformers, as well as modeling of temperature dependences ;
- visualization of weaknesses in the network based on the results of the voltage level and load factor.

In addition to the basic modules, the software also includes the following modules:

1) Relay protection modules:
- modeling of current protection with endurance of time;
- advanced protection modeling;
- calculation of remote protection installations;
- assessment of protection selectivity.

2) Analysis modules:
- calculation of operating points / time series;
- strategic network planning;
- calculation of economic efficiency;
- engine start;
- multiple injuries;
- time series data interface.

3) Modules of multiple calculations:
- analysis of post-emergency modes and restoration of power supply;
- probabilistic calculation of reliability;
- power reserve assessment;
- network test under load;
- placement and determination of energy storage parameters.

4) Optimization and planning modules:
- optimal network structure;
- search for the optimal position of normally open points;
- reactive power compensation optimization;
- Volt-Var optimization;
- load balancing.

5) Modules for working with the network model and workflow administration:
- multi-user database;
- association of models;
- equivalence.

Separately, we will focus on the module of optimization and planning, namely - the optimization of reactive power compensation.

Optimal reactive power compensation has a positive effect on the network. This usually brings the following benefits: reduction of the total transmitted power and the corresponding reduction in the load of network elements; reduction of load power losses in the system; improving the voltage curve and reducing voltage limits; due to the reduction of the load of the elements there is a possibility of a point of modernization aimed at increasing network bandwidth; reduction of reactive power consumption costs.

The reactive power compensation optimization module in PSS®SINCAL offers methods for optimizing the use of existing equipment by finding the optimal switching points for reactive power compensation.

ISSN 2224-0349 (print)

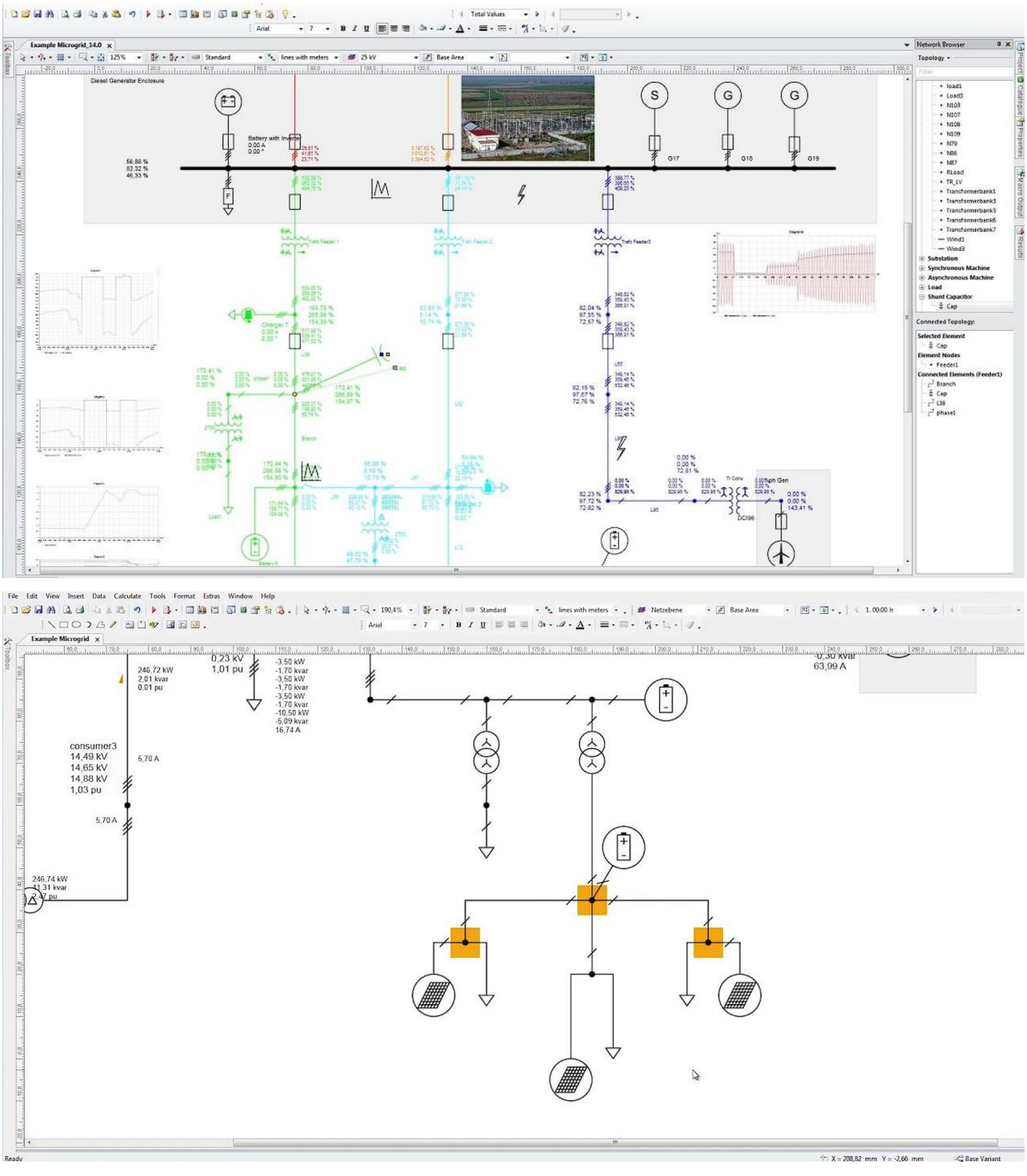

Figure 1 – PSS®SINCAL software interface

The series of calculations of the established mode determines the amount of reactive power consumed by the network. In each cycle of calculations of the established mode the part of necessary reactive power flowing through power transformers is compensated. The reactive power consumed by the network can be inductive or capacitive. The calculation of reactive power consumption is performed for selected voltage classes. Shunt reactors or capacitors are connected to low voltage transformer busbars for those parts of the network where reactive power compensation is required to achieve a given power factor. PSS®SINCAL can also offer standard device ratings for reactive power compensation based on the types specified in the equipment library.

The purpose of this optimization method is to achieve a minimum level of losses in the network by placing a given number of capacitors. PSS®SINCAL can determine the optimal locations for compensation devices given the cost of installing capacitors and the expected savings from loss reduction. Return on investment is calculated on the basis of costs and savings.

ETAP. ETAP is a software from the American company Operation Technology (Fig. 2) [9].

For over 30 years, the company has been successfully providing a comprehensive and widely used corporate solution for: generation; transfers; distribution; industry; transport; low voltage systems.

ETAP software specializes in: modeling; design; monitoring and management; training of dispatchers; optimization and automation of energy systems.

From this software we are interested in 2 modules, namely the transmission and distribution of electricity.

ETAP Grid ™ integrates network design software with detailed substation models, network topology processing, transmission network analysis, SCADA systems and real-time transmission network management.

The software module of the distribution category uses - analysis of the distribution network, planning and optimization of the network.

Distribution system analysis and optimization tools are used for network planning, modeling and forecasting of system responses using schematic or geospatial representations.

The transmission module includes the following tools:

1) Development of electricity transmission networks:

- modeling and visualization of networks (electric single-line diagram, modeling of power transmission equipment, geospatial electrical scheme of power transmission networks);
- solutions for the analysis of the power transmission system (calculation of the mode for power transmission networks, unified calculation of the established mode, analysis of the consequences of emergency modes (N-1, N-2), calculation of short-circuit currents, asymmetric short-circuit, voltage stability);
- transmission network optimization (optimal set mode, transformer soldering optimization);
- dynamic and transient processes (dynamic stability, custom dynamic models, transient electromagnetic processes, dynamic evaluation of parameters and settings, evaluation of engine parameters, generator start);
- renewable energy sources (solar panels, windmills);
- overhead power lines (line constants, analysis of gravity and sags of power lines, allowable current load of power lines);
- determination of transformer parameters and optimization of soldering;
- grounding systems.

2) Protection of electricity transmission networks:

- coordination of remote protections;
- analysis and calculation of arc flash;
- automated protection and coordination system;
- sequence of relay protection operation;
- identification of branches of protection and coordination / selectivity;
- coordination and selectivity of protective devices.

3) Electricity transmission control system:

- SCADA for electrical networks;
- electrical network management system;
- intelligent load shedding;
- power consumption monitoring and process simulator.

The distribution module includes the following tools:

1) Analysis of distribution networks:

- asymmetric mode;
- load location;
- isolation of short circuits and resumption of work;
- arc flash;
- unified calculation of the established mode in time;
- asymmetric short circuit;
- engine start;
- arc flash calculation;
- system reliability assessment.

2) Network optimization:

- optimal set mode (minimization of active and reactive losses, minimization of fuel costs, minimization of energy costs, maximization of system performance, optimization of power exchange with other systems (on-site creation, utilities, IPP and power grids), minimization of load shedding, minimization fuel in the generator with different flow models and fuel profiles, power control generators MW and MVAr , AVR parameters within the specified limits, voltage regulators within the specified limits, selection of capacitors within the specified limits, maximum safety indices of voltage and overflow control parameters)
- Switching optimization (optimizes the loss of active power in the system to reduce operating costs, minimizes voltage fluctuations and reduces the number of cases of unacceptable voltage, minimizes overload and reduces overloaded equipment, minimizes overload and reduces overloaded equipment, balances feeder load and determines strong load switching loaded substations or feeders through partitioning points, limits the load on some critical feeders by switching part of their load on other feeders thereby increasing system reliability, lists recommended switching operations, displays water information on network loads and active power losses before and after the optimization process shows a list of overloaded equipment for the original and received network configuration, displays the voltage deviation for the original and received network configuration, automatically creates and maintains optimal configuration);

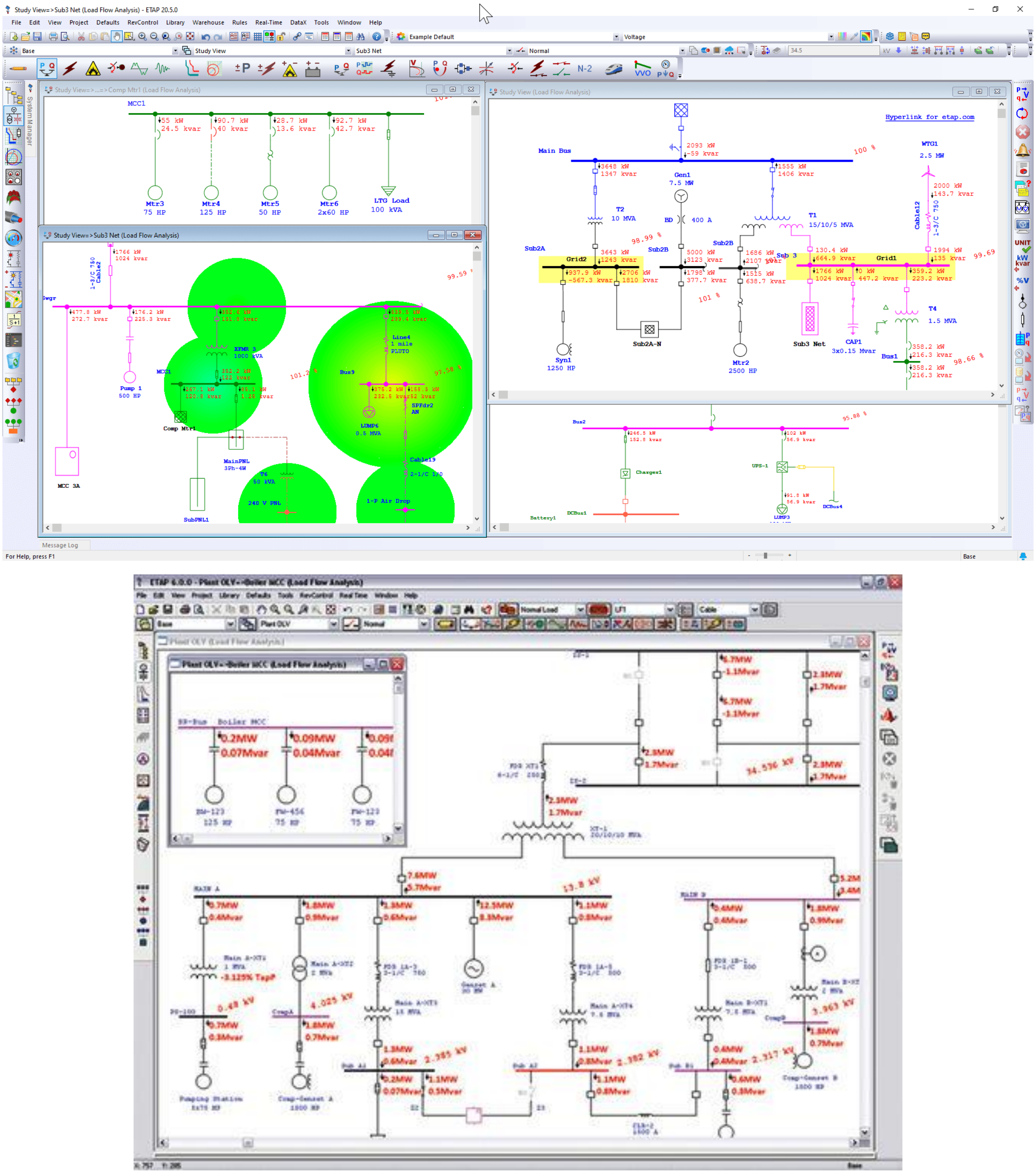

Figure 2 – ETAP interface

• V / VAR optimization (VVO) and conservative voltage reduction, maximum voltage and flow safety , minimum reactive power and demand losses by CVR, optimizes the power factor for the entire substation or individual feeders depending on the time of day, static load profile or average load, generator reactive power settings and inverter settings, capacitor or stack (SVC) settings, switching capacitors within set limits, voltage regulation by LVN within set limits, substation optimization settings during peak and normal operating periods for large customers, automatic control power factor for light loads such as holidays and weekends, protection of the feeder by voltage level with restrictions)

• optimal placement of capacitors.

Separately, consider the module of optimal placement of capacitors.

This module allows engineers to strategically position capacitors to maintain voltage and adjust power factor, minimizing installation and long-term operation costs.

The advanced graphical interface gives users the flexibility to control the capacitor placement process and graphically view the results. An accurate approach to the calculation automatically determines the best places and the amount of capacitor power. In addition, it reports capacity reductions and expected savings during the planning period by reducing reactive power losses.

Main characteristics of the module: optimal location and power of capacitors; minimization of installation and operation costs; voltage and / or power factor targets; minimum, maximum and average load; free bandwidth and cost savings; review of the impact of the capacitor on the system; condenser control; flexible restrictions.

That is, this module allows you to find the best location of capacitors and choose the amount of their power, which minimizes the total cost of installation and operation.

It is possible to find the global optimal solution by processing radial or annular balanced networks, as well as to analyze the method of capacitor control and review the impact of the capacitor on the system.

Capacitor placement targets are selected by the user: voltage maintenance, power factor correction or both.

Capacitor types and battery sizes are selected by the user from an existing database.

Additionally, the user determines the planning period, in the context of which occurs: determination of savings during the entire planning period; determining savings savings; determining the cost of operating the capacitor and annual savings during the planning period.

PowerFactory. PowerFactory – software from the German company DIgSILENT GmbH (Fig. 3).

PowerFactory is the leading software for energy system analysis to analyze: generation; transfers; distribution; industrial systems [10].

It covers the full range of functionality from standard features to highly sophisticated and advanced applications, including wind power, distributed generation, real-time simulation, and performance monitoring for system testing and monitoring.

PowerFactory is easy to use, fully compatible with Windows and combines reliable and flexible system modeling capabilities with state-of-the-art algorithms and a unique database concept. In addition, thanks to its flexibility for scripts and interface, PowerFactory is ideal for integrated and highly automated solutions.

From this software we are interested in 2 modules:

1) Transmission module.

PowerFactory offers a complete set of features for studying large interconnected power supply systems and meeting these emerging needs. Its fast and reliable simulation algorithms can be applied to any AC or DC network topology and support modeling of new technologies such as converter-based power generation, FACTS, voltage converters (VSC), HVDC, cables and overhead lines, DC switches. , filters and different types of MW- and MBAR - controllers and virtual power plants.

To support such a rich data model, PowerFactory comes with comprehensive scheduling tools. Operation scripts can be used to save waypoints, thus allowing the user to learn different scenarios with just a few clicks. Network variations with time-related expansion stages allow the user to model network development projects, including (decommissioning) power system equipment. By simply changing the study time, the correct network configuration will be automatically used for calculations.

PowerFactory is also ideal for scheduling the transmission system. It integrates a complete set of tools to support automatic and parallel network security analysis, such as ENTSO-E D2CF / DACF / IDCF, and shutdown planning. Multiple interfaces (API, DGS, CIM) and flexible scripting languages (DPL, Python) provide seamless integration with existing systems and compliance with the ENTSO-E CGMES data exchange standard.

Related features and functions: outstanding opportunities for energy system modeling; support for multiple network diagrams with direct connection to network elements; support for models of circuit breakers and busbars; full integration of network model, analysis and reporting; analysis of unforeseen circumstances; stability analysis (RMS and modal analysis); electromagnetic transients (EMT); analysis of sensitivity / distribution factors, including PTDF; shutdown planning harmonics / Power quality; optimization of dispatching; PV / QV curve calculations; capacity analysis; network reduction; optimal power flow; ultra-fast quasi -dynamic modeling based on neural network.

2) Distribution module.

New problems, such as power backflow and increased voltage due to distributed generation, as well as the integration of e-mobility have led to increased complexity in the planning and operation of distribution networks. Complex and comprehensive network optimization tools are required to process the related analysis.

To solve these problems , PowerFactory offers a wide range of powerful tools and features. Using built-in interfaces, networking and entering measurement values can be achieved with GIS and SCADA data. Based on this data, you can analyze the current state of the network, for example, to estimate the hosting capacity for load and generation. Numerous functions are available for further network optimization, such as open point optimization, voltage profile optimization, phase balance optimization, and optimal equipment placement.

The user-friendly time scan simulation feature facilitates the analysis of the impact on the network infrastructure of both traditional generation and renewable energy sources, taking into account unstable distributed generation and storage systems with user-defined controls.

Models: load models using standard load profiles or smart meter data; models of photovoltaic systems based on solar radiation, electric cars, batteries, etc; innovative equipment (on-load tap-changer, voltage stabilizers, reactive power control circuits, etc.); dynamic and topologically dependent feeders required for many distribution systems.

User interface: geographic charts with public and special cartographic services as a background; stress profile sections for feeders.

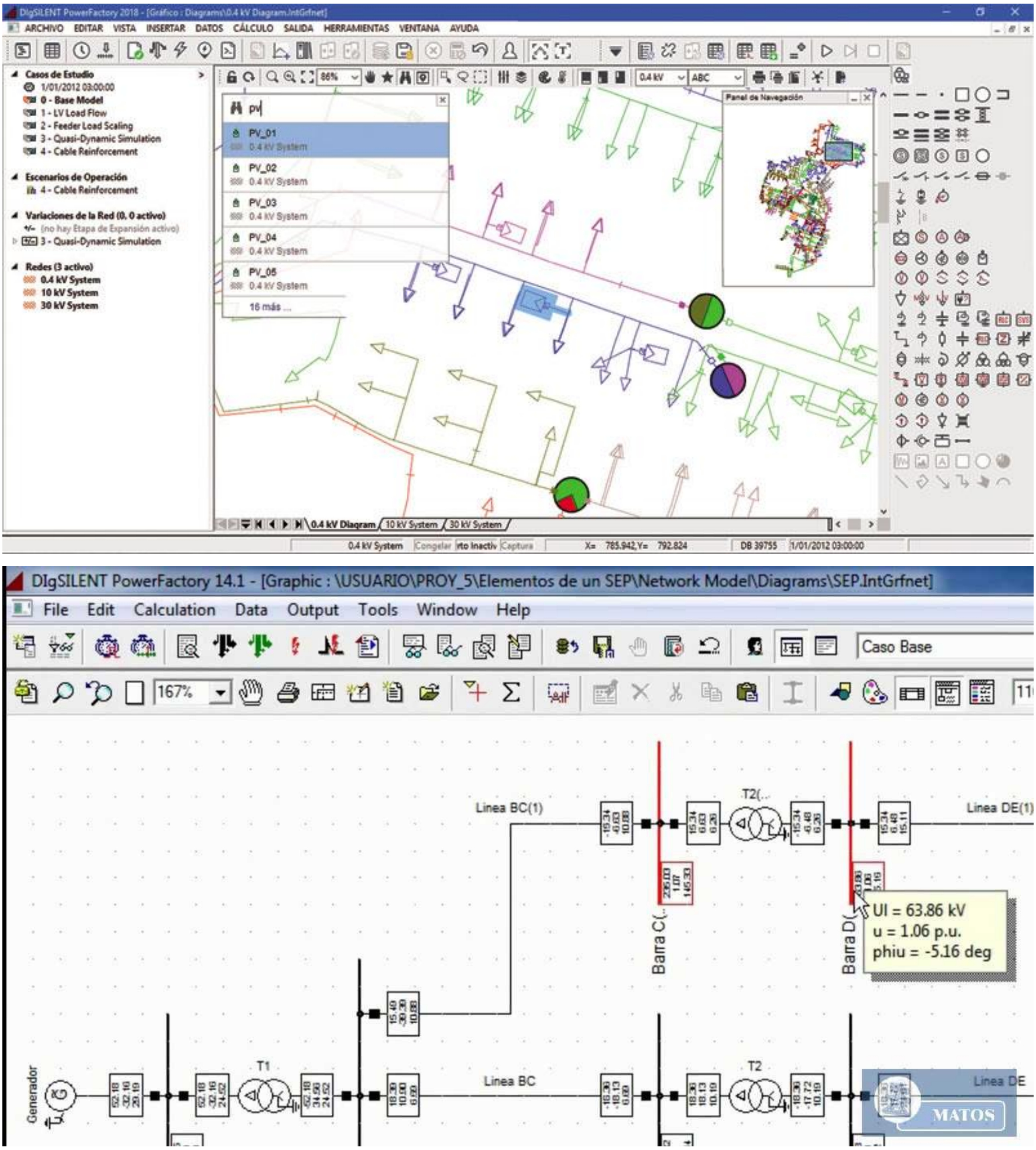

Figure 3 – PowerFactory

Analysis and optimization: probabilistic analysis with stochastic modeling of distributed generation and demand; optimization of voltage profile for bidirectional power flows; reliability analysis and optimal power recovery; quality of electricity and analysis of harmonics; protection functions; tools of economic analysis; assessment of the connection request; quasi -dynamic modeling; determining the cable size and reduction factor; feeder load scaling; hosting capacity analysis; phase balance optimization; voltage failure assessment; calculation of the highway.

Equipment placement functions: optimal placement of equipment for voltage regulators; batteries; remotely controlled switches; reclosers; capacitors.

Separately, we will dwell on the tools associated with reactive power compensation.

Optimal capacitor placement: determination of optimal locations, types, phase technology and sizes of capacitors; economic assessment taking into account the cost of losses against the cost of installation at predetermined voltage limits; support for load changes due to characteristics.

Reactive power optimization: minimization of total or partial losses in the network; maximization of reactive power reserve; reactive power optimization (internal point method).

Various controls, such as: reactive power of the generator; transformer and shunt taps; static systems.

Flexible restrictions, such as: limits of flow and voltage of the branch; limits of reactive power of the generator; reactive power reserve; border flows.

Conclusions. Analyzing the above software, their functions and capabilities, we can conclude that their use to design new systems or optimize existing ones will significantly increase the level of work and improve the work of specialists in relevant fields. Also, given the availability of various modules and tools, all software can facilitate various stages of technical calculations and save a lot of time.

Regarding the use of this software for calculations and optimization of electrical networks for reactive power flow modes and consideration of compensating devices - PSS®SINCAL software is the most suitable option, because it meets most of the requirements listed at the beginning of the article and has a wider range of tools and modes regarding reactive power compensation and its optimization in existing networks.

References

1. B. G. Assefa and Ö. Özkasap, “A survey of energy efficiency in SDN: Software-based methods and optimization models,” *Journal of Network and Computer Applications*, vol. 137, pp. 127–143, Jul. 2019, doi: https://doi.org/10.1016/j.jnca.2019.04.001.
2. J. Son, A. V. Dastjerdi, R. N. Calheiros, X. Ji, Y. Yoon, and R. Buyya, “CloudSimSDN: Modeling and simulation of software-defined cloud data centers,” in *2015 15th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid)*, Shenzhen, China, May 4–7, 2015. pp. 475–484, doi: https://doi.org/10.1109/ccgrid.2015.87.
3. S. Shevchenko, D. Danylchenko, D. Kuznetsov, and S. Petrov, “Use of capacitor batteries to improve the quality of electrical energy,” in *2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek)*, Kharkiv, Ukraine, Sep. 13–17, 2021. pp. 666–669, doi: https://doi.org/10.1109/khpiweek53812.2021.9570023.
4. D. O. Danylchenko and D. S. Kuznetsov, “Osoblyvosti vprovadzhennia kondensatornykh ustanovok na PS oblenerho Ukrainy [Features of the introduction of capacitor installations at the substations of Ukrainian regional power companies],” in *IV International Scientific and Technical Conference “Energy Efficiency and Energy Security of Electric Power Systems” (EEES-2020)*, Kharkiv, Ukraine, Nov. 10–13, 2020. pp. 72–75. (in Ukrainian)
5. D. O. Danylchenko and D. S. Kuznetsov, “Kompensatsiia reaktyvnoi elektroenerhii na suchasnykh pidpryiemstvakh [Compensation of reactive electricity at modern enterprises],” in *XXVII International Scientific-Practical Conference MicroCAD-2019*, Kharkiv, Ukraine, May 15–17, 2019. p. 149. (in Ukrainian)
6. Y. Tomashevskyi, O. Burykin, V. Kulyk, J. Malogulko, and V. Hrynyk, “Distribution electrical network information system based on the smart metering concept using standard load schedules,” *Technical Sciences and Technologies*, no. 3(21), pp. 229–241, 2020, doi: https://doi.org/10.25140/2411-5363-2020-3(21)-229-241. (in Ukrainian)
7. Z. Wang and R. S. Srinivasan, “A review of artificial intelligence based building energy use prediction: Contrasting the capabilities of single and ensemble prediction models,” *Renewable and Sustainable Energy Reviews*, vol. 75, pp. 796–808, Aug. 2017, doi: https://doi.org/10.1016/j.rser.2016.10.079.
8. Ravishankar Rao, S. Vrudhula, and D. N. Rakhmatov, “Battery modeling for energy-aware system design,” *Computer*, vol. 36, no. 12, pp. 77–87, Dec. 2003, doi: https://doi.org/10.1109/mc.2003.1250886.
9. V. De Maio, R. Prodan, S. Benedict, and G. Kecskemeti, “Modelling energy consumption of network transfers and virtual machine migration,” *Future Generation Computer Systems*, vol. 56, pp. 388–406, Mar. 2016, doi: https://doi.org/10.1016/j.future.2015.07.007.
10. S. Naji et al., “Estimating building energy consumption using extreme learning machine method,” *Energy*, vol. 97, pp. 506–516, Feb. 2016, doi: https://doi.org/10.1016/j.energy.2015.11.037.

Received 21.11.2022

Відомості про автора (-ів) / About the Author (-s)

Sergey Shevchenko (Шевченко Сергій Юрійович) – Doctor of Technical Sciences, Professor, National Technical University “Kharkov Polytechnic Institute”, Head of the Department of Electric power transmission; Kharkiv, Ukraine; ORCID: https://orcid.org/0000-0002-9658-7787; e-mail: Sergii.Shevchenko@khpi.edu.ua.

Dmytro Danylchenko (Данильченко Дмитро Олексійович) – Candidate of Technical Sciences (PhD), Docent, National Technical University “Kharkov Polytechnic Institute”, Associate Professor at the Department of Electric power transmission; Kharkiv, Ukraine; ORCID: https://orcid.org/0000-0001-7912-1849; e-mail: dmytro.danylchenko@khpi.edu.ua.

Dmytro Kuznetsov (Кузнєцов Дмитро Сергійович) – PhD Student at the Department of Electric power Transmission, National Technical University “Kharkov Polytechnic Institute”; Kharkiv, Ukraine; e-mail: dmytro.kuznetsov@ieee.khpi.edu.ua.

Mohamed Zaidan Qawaqzeh (Кавакзех Мохамед Зайдан) – PhD, Associate Professor, Al-Balqa Applied University, Head of the Department of Technical Sciences; Ma’an, Jordan; ORCID: https://orcid.org/0000-0001-7027-5577; e-mail: qawaqzeh@bau.edu.jo.

Oleksandr Miroshnyk (Мірошник Олександр Олександрович) – Doctor of Technical Sciences, Professor, State Biotechnological University, Head of the Department of Energy supply and management, Kharkiv, Ukraine; ORCID: https://orcid.org/0000-0002-6144-7573; e-mail: omiroshnyk@ukr.net.