

MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION
Federal State Autonomous Educational Institution for Higher Education
«North-Caucasus Federal University»

APPROVED BY

Dean of FPE of NCFU
Candidate of Technical Sciences,
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COURSE SYLLABUS
«Advanced Analysis of Power Systems»

Field of study	<u>13.04.02 Electric Power Engineering and Electrical Engineering</u>
Specialization (Profile)	<u>Training Program of Electrical Engineering</u>
Year of commencement of studies	<u>2026</u>
Mode of study	<u>full-time</u>
Implemented in semester(s)	<u>3</u>

DEVELOPED BY:

Candidate of Technical Sciences, Associate
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1. Purpose and objectives of studying the discipline (module)

The purpose of the discipline "Advanced Analysis of Power Systems" is to provide students with a deep understanding of the theoretical foundations, mathematical models, and computational methods required for the comprehensive analysis, modeling, and optimization of modern electric power systems (EPS). The course is designed to equip students with the skills necessary to ensure the reliable, secure, and economically efficient operation of EPS in the context of global energy transformation, including the integration of renewable energy sources, distributed generation, and power electronics.

Objectives of the discipline

To achieve the stated purpose, the discipline pursues the following objectives:

To develop a deep understanding of EPS mathematical models.

- To study the detailed mathematical representation of EPS components (generators, transformers, transmission lines) and the derivation of steady-state equations in both current and power mismatch forms.

To master advanced computational methods for power flow and state estimation.

- To learn and practically implement robust numerical algorithms, primarily the Newton-Raphson method and Weighted Least Squares (WLS) state estimation, for solving large-scale, non-linear systems.
- To understand the principles of convergence, computational efficiency, and the application of sparse matrix techniques.

To acquire skills in stability and security analysis.

- To analyze static and dynamic stability of power systems.
- To apply methods for calculating power transfer limits and performing transient stability analysis to assess the system's ability to withstand severe disturbances.

To learn techniques for optimization of power system operation.

- To formulate and solve economic dispatch and optimal power flow (OPF) problems.
- To understand how to minimize generation costs or system losses while satisfying a complex set of operational constraints.

To master methods for fault analysis and system protection.

- To apply symmetrical components theory for the calculation of short-circuit currents in unbalanced fault conditions.
- To understand the impact of faults on system operation and protection schemes.

To develop proficiency in data-driven analysis and bad data processing.

- To implement algorithms for bad data detection and identification within the state estimation process to ensure the reliability of input data from SCADA/PMU systems.

To gain practical experience with industry-standard software tools.

- To use specialized software (e.g., MATLAB, Python with scientific libraries, or commercial packages like DIgSILENT PowerFactory) for modeling, simulation, and analysis of complex power networks.

To prepare for addressing modern challenges in power engineering.

- To analyze the impact of high penetration of inverter-based resources (solar, wind), HVDC links, and flexible AC transmission systems (FACTS) on traditional methods of power system analysis and control.

2. Place of the discipline (module) in the structure of the educational program

The discipline "Optimization Methods in Electric Power Engineering" belongs to the part formed by the participants of educational relations within the educational program. It is studied in the 2th semester.

3. List of planned learning outcomes for the discipline (module), mapped to the planned outcomes of the educational program

Competency code and formulation	Indicator code and formulation	Planned learning outcomes for the discipline (module) describing the stages of competency and indicator formation
PC-2 Capable of participating in the design of objects of professional activity	ID-1 PC-2. Performs calculation and analysis of the economic and technical characteristics of the object being designed;	The student knows the principles of calculating and analyzing the technical and economic characteristics of power system objects. They are able to perform power flow analysis, assess system stability, and apply optimization methods to minimize costs and losses. Furthermore, the student owns the skills to justify design decisions by evaluating the economic and technical performance of the proposed power system configuration.

4. Scope (credit load) of the academic discipline (module) and forms of control

Total study load: 4 credits / 144 academic hours	In academic hours
Contact work:	36
Lectures / of which practical training	0 / 0
Laboratory works / of which practical training	0 / 0
Practical classes / of which practical training	36/ 0
Independent work	108
Forms of control:	
Exam	—
Pass/Fail (Credit)	3th semester
Graded Pass/Fail (Credit with grade)	—
Course project/paper	—

* The discipline (module) provides for the use of e-learning and distance educational technologies (unless otherwise stipulated by the educational standard).

5. Content of the discipline (module), structured by topics (sections), indicating the number of hours and types of classes

№	Section (topic) of the discipline and brief content	Formed competencies and indicators	Full-time form				Forms of ongoing progress control
			Contact work of students with the teacher / of which in the form of practical training, hours			Independent work, hours	
			Lectures	Practical classes	Laboratory works		
1	Introduction to Modern EPS Analysis. Goals, objectives of the discipline. Overview of modern challenges: decentralization, electrification, cybersecurity.	ID-1 PC-2	–	1	–	4	Interview
2	Mathematical Foundations. Linear algebra and matrix analysis in power engineering. Properties of nodal admittance and impedance matrices.	ID-1 PC-2	–	1	–	4	Interview
3	Network Elements Modeling. Equivalent circuits of transmission lines and transformers. Accounting for mutual inductance and distributed parameters.	ID-1 PC-2	–	1	–	4	Interview
4	Steady-State Equations. Nodal equations in power and current mismatch forms.	ID-1 PC-2	–	1	–	4	Interview
5	Methods for Solving Nonlinear Equations. Newton-Raphson method: algorithm, convergence, choice of initial approximation.	ID-1 PC-2	–	1	–	4	Interview
6	Sensitivity and Limiting Mode Analysis. Calculation of static stability limits. Sensitivity analysis of voltages to parameter changes.	ID-1 PC-2	–	1	–	4	Interview
7	Optimization of EPS Operation. Problem statement. Criteria: minimum losses, minimum generation cost.	ID-1 PC-2	–	1	–	4	Interview
8	Unbalanced Mode Analysis. Method of Symmetrical Components. Calculation of currents and voltages for ground faults.	ID-1 PC-2	–	1	–	4	Interview
9	Transient Processes in EPS. Classification of transients. Dynamics equations of a synchronous machine (Park's equations).	ID-1 PC-2	–	1	–	4	Interview
10	Dynamic Stability. Equal Area Criterion. Analysis of dynamic stability during short circuits and reclosing cycles.	ID-1 PC-2	–	1	–	4	Interview
11	Small Oscillations and Droop. Small-signal equations. Eigenvalue analysis for system damping assessment.	ID-1 PC-2	–	1	–	4	Interview

12	State Estimation (SE). Purpose and tasks of state estimation. Mathematical formulation of the problem.	ID-1 PC-2	–	1	–	4	Interview
13	State Estimation Algorithms. Weighted Least Squares (WLS). Algorithm using the Jacobian matrix.	ID-1 PC-2	–	1	–	4	Interview
14	Topological Analysis and Bad Data. Detection and identification of gross errors in measurements (Bad Data Detection and Identification).	ID-1 PC-2	–	1	–	4	Interview
15	Future Prospects. Impact of power electronics (FACTS, HVDC) on analysis methods. Artificial Intelligence in grid operation and control.	ID-1 PC-2	–	1	–	4	Interview
16	Ybus Matrix Formation. Algorithm implementation for constructing the nodal admittance matrix for a given network scheme.	ID-1 PC-2	–	1	–	4	Interview
17	Gauss-Seidel Method Implementation. Implementation of the iterative method on a test network.	ID-1 PC-2	–	1	–	4	Interview
18	Newton-Raphson Method Implementation. Implementation for steady-state calculation with convergence analysis.	ID-1 PC-2	–	1	–	4	Interview
19	Power Transfer Limit Calculation. Determination of the static stability limit for a transmission line.	ID-1 PC-2	–	1	–	3	Interview
20	Load Dispatch Optimization Problem. Implementation of the Lagrange multiplier or gradient method to minimize network losses.	ID-1 PC-2	–	1	–	3	Interview
21	Unbalanced Short-Circuit Analysis. Calculation of fault currents using symmetrical components for different fault types.	ID-1 PC-2	–	1	–	3	Interview
22	Short-Circuit Current Calculation in a Complex Network. Simulation of fault currents for remote faults with infeed from adjacent sources.	ID-1 PC-2	–	1	–	3	Interview
23	Transient Process Modeling. Numerical integration of generator dynamics equations during a network disturbance (e.g., load rejection).	ID-1 PC-2	–	1	–	3	Interview
24	Dynamic Stability Analysis (Equal Area Criterion). Construction of power-angle curves and calculation of the critical fault clearing angle.	ID-1 PC-2	–	1	–	3	Interview
25	System Droop Analysis. Simulation of frequency and voltage changes with load variation, evaluation of turbine and AVR droop coefficients.	ID-1 PC-2	–	2	–	3	Interview
26	State Estimation: Weighted Least Squares (WLS). Implementation of the WLS algorithm for state calculation	ID-1 PC-2	–	2	–	3	Interview

	based on measurement data.						
27	Jacobian Matrix Formation and Linearization. Practical implementation of the Jacobian matrix calculation for power flow equations within the SE algorithm.	ID-1 PC-2	–	2	–	3	Interview
28	Bad Data Detection (BDD). Implementation of a statistical test (Chi-square or t-test) to identify gross errors in the measurement set.	ID-1 PC-2	–	2	–	3	Interview
29	Bad Data Identification (BDI). Application of exclusion methods (e.g., Largest Normalized Residual) to identify and remove erroneous measurements from the calculation.	ID-1 PC-2	–	2	–	3	Interview
30	Network Topological Analysis. Development of an algorithm for assessing network connectivity and verifying the N-1 criterion using graph theory (Breadth-First/Depth-First Search).	ID-1 PC-2	–	2	–	3	Interview
	TOTAL		0	36	–	108	144

6. Assessment tools for ongoing progress control and intermediate assessment of students in the discipline (module)

The assessment tools (AT) for ongoing progress control and intermediate assessment of students in the discipline "Advanced Analysis of Power Systems" are based on the list of competencies to be acquired, indicating the stages of their formation during the study of the discipline (module). The AT ensures objective monitoring of the achievement of the planned learning outcomes. The AT includes:

- a description of indicators and criteria for assessing competencies at various stages of their formation, and a description of grading scales;
- methodological materials defining the procedures for assessing knowledge, skills, abilities, and/or experience of activities that characterize the stages of competency formation;
- standard control tasks and other materials necessary for assessing knowledge, skills, and the level of mastery of the competencies being formed during the study of the discipline (module).

The assessment tools are an appendix to this discipline (module) program.

7. Methodological guidelines for students on mastering the discipline

When starting work, each student should take into account the following provisions.

The discipline (module) is organized thematically; each topic represents a logically complete section.

Practical classes are conducted to consolidate the acquired information and develop skills in applying it to solve practical problems in the relevant subject area.

Students' independent work is aimed at independently studying additional material, preparing for practical and laboratory classes, as well as completing all types of independent work.

For successful mastery of the discipline, it is necessary to complete all types of independent work using the recommended information sources.

8. Educational, methodological, and informational support of the discipline

8.1. List of basic and additional literature required for mastering the discipline (module)

8.1.1. List of basic literature:

1. Power System Analysis and Design by J. Duncan Glover, Thomas Overbye, and Mulukutla S. Sarma // Pacific Grove, CA : Wadsworth/Thomson Learning. – 2002. – 656p.
2. Power System Stability and Control by Prabha Kundur (with contributions from the Power System Engineering Research Center) // McGraw-Hill Education, 1994.– 1176p.
3. Power System State Estimation: Theory and Implementation by Ali Abur and Antonio Gómez Expósito // CRC Press, 2004. – 327p.
4. Optimization Methods Applied to Power Systems (I). MDPI, 2019.
5. Optimization Methods Applied to Power Systems (II). MDPI, 2022.

8.1.2. List of additional literature:

1. Computational Methods for Electric Power Systems by By Mariesa L. Crow CRC Press, 2015 pp. 345
2. Python for Data Analysis by Wes McKinney (3rd Edition, 2022) – Pandas and data handling.

8.2. List of educational and methodological support for students' independent work in the discipline (module)

1. Methodological Guidelines for Practical Classes in the Discipline "Advanced Analysis of Power Systems" for Students in the Field of Study 13.04.02 Electric Power Engineering and Electrical Engineering / Compiled by E. G. Zelenskii. – Stavropol: North Caucasus Federal University, 2026.
2. Methodological Recommendations for Organizing Independent Work of Students in Preparation for Classes in the Fields of Study: 13.04.02 Electric Power

8.3. List of resources of the information and telecommunications network "Internet" necessary for mastering the discipline (module)

1. <http://biblioclub.ru> – Electronic Library System "University Library Online"
2. <http://catalog.ncstu.ru> – Electronic Catalog of the Association of Electronic Libraries of Educational Institutions and Organizations of the North Caucasus Federal District
3. <http://www.iprbookshop.ru> – Electronic Library System
4. <http://window.edu.ru/> – Unified Window of Access to Educational Resources
5. <http://openedu.ru> – National Online Learning Portal "Open Education"

9. List of information technologies used in the educational process for the discipline (module), including the list of software and information reference systems

During lectures, computer equipment and presentation of multimedia materials are used. In seminar and practical classes, students present presentations prepared by them during independent study hours.

Information reference systems:

Information reference and information legal systems used in the study of the discipline:

1	ConsultantPlus – http://www.consultant.ru/
2	https://minenergo.gov.ru/ – Official website of the Ministry of Energy of Russia

Software:

1	Alt Workstation 10
2	Alt Workstation K
3	Alt Server
4	Office suite – R7-Office

10. Description of the material and technical base necessary for the implementation of the educational process in the discipline (module)

Practical classes	Classroom for conducting training sessions, equipped with multimedia equipment and technical teaching aids.
Independent work	A room for independent work of students, equipped with computer equipment with the ability to connect to the Internet and access to the university's electronic information and educational environment.

11. Features of mastering the discipline (module) by persons with disabilities

Students with disabilities are provided with special textbooks, teaching aids and didactic materials, special technical means of learning for collective and individual use, services of an assistant who provides students with the necessary technical assistance, as well as sign language interpreting and typhlo-sign language interpreting services.

Mastering the discipline (module) by students with disabilities may be organized together with other students, as well as in separate groups.

Mastering of the discipline (module) by students with disabilities is carried out taking into account the characteristics of psychophysical development, individual capabilities and health status.

In order to ensure accessibility of higher education under the educational program for persons with disabilities when mastering the discipline (module), the following is provided:

1) For persons with visual disabilities:

- presence of an assistant who provides the student with the necessary technical assistance taking into account individual characteristics (helps to take a seat, move around, read and complete the task, including writing under dictation);

- written assignments, as well as instructions on the procedure for their completion, are formatted in enlarged font;
- special textbooks, teaching aids and didactic materials (with large print or audio files);
- individual uniform lighting of at least 300 lux;
- if necessary, a magnifying device is provided to the student for completing the task

2) For persons with hearing disabilities:

- presence of an assistant who provides the student with the necessary technical assistance taking into account individual characteristics (helps to take a seat, move around, read and complete the task, including writing under dictation);
- provision of collective sound amplification equipment; if necessary, the student is provided with individual sound amplification equipment;
- provision of appropriate sound means of information reproduction.

3) For persons with musculoskeletal disorders (including those with severe motor impairments of the upper limbs or absence of upper limbs):

- written assignments are performed on a computer with specialized software or dictated to an assistant;
- at the student's request, assignments may be completed orally.

12. Features of implementing the discipline using distance educational technologies and e-learning

According to Part 1 of Article 16 of Federal Law No. 273-FZ of December 29, 2012 "On Education in the Russian Federation," e-learning is understood as the organization of educational activities using information contained in databases and used in the implementation of educational programs, information technologies and technical means that ensure its processing, as well as information and telecommunications networks that ensure the transmission of said information through communication lines and the interaction of students and teaching staff. Distance educational technologies are understood as educational technologies implemented primarily using information and telecommunications networks with indirect (remote) interaction between students and teaching staff.

The discipline may be implemented using distance educational technologies and e-learning in whole or in part. The components of the educational and methodological set of the discipline (syllabus, assessment and methodological materials, forms of certification) implemented using distance educational technologies and e-learning contain an indication of their use.

When organizing educational activities using distance educational technologies and e-learning, asynchronous and synchronous methods of interaction between participants in educational relations via the information and telecommunications network "Internet" may be provided.

When using distance educational technologies and e-learning, the schedule for the discipline indicates: methods of interaction between participants in educational relations via the information and telecommunications network "Internet" (VCS – video conferencing, ET – electronic testing); links to the electronic information and educational environment of NCFU, to educational platforms and resources of other organizations to which open access is provided via the information and telecommunications network "Internet"; for synchronous learning – the time of online classes and the instructors; for asynchronous learning – the authors of online courses.

When organizing intermediate assessment using distance educational technologies and e-learning, the Methodological Recommendations on the use of technical means ensuring the objectivity of results during intermediate and state final assessment in higher education programs – bachelor's programs, specialist's programs and master's programs using distance educational technologies (Letter of the Ministry of Science and Higher Education of the Russian Federation dated December 7, 2020 No. MN-19/1573-AN "On sending methodological recommendations") are applied.

The implementation of the discipline using e-learning and distance educational technologies is carried out using the electronic information and educational environment of NCFU,

to which students have access via the information and telecommunications network "Internet", or using resources of other organizations, including platforms that provide services for video conferencing, online meetings and distance learning (MTS-Link), as well as using the capabilities of social networks to facilitate communication between students and instructors.

The educational and methodological support of the discipline implemented using e-learning and distance educational technologies includes the syllabus, educational and methodological manuals or a lecture course, methodological guidelines for performing various types of learning activities provided for by the discipline, and other educational and methodological materials posted in the electronic information and educational environment of NCFU, all presented in electronic form.