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Teaching Contemporary Power Distribution and Industrial Networks in Higher Education Vocational Studies

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Abstract**—**The paper shows the development and implementation of the syllabus of the subject 'Distribution and Industrial Networks', attended by the vocational specialist Year 4 students of the Electric Power Engineering study programme at the Higher Education Technical School of Vocational Studies in Novi Sad. The aim of the subject is to equip students with the knowledge necessary for planning, exploitation and management of distributive and industrial electric power networks in an open electricity market environment. The results of the evaluation of educational outcomes on the subject are presented and discussed.

Keywords**—**Engineering education, power distribution network, syllabus implementation, outcome evaluation.

I. Introduction

LIBERALIZATION and deregulation of the electric power sector has brought new challenges for the electric distribution companies, such as stringent demands for reliable electricity supply, numerous requests from investors for connection of small renewable generators, severe natural disasters, limited budgets for network development, and ageing of the workforce, etc.

Recent environment-driven increase in distributed generation has had a huge impact on keeping stable voltage conditions throughout the system and on maintaining the supply of every consumer within the contracted power quality. Another notable challenge is to maintain the compatibility of the existing power supply system with new technologies of the distributed generation. Planning of the power network development must satisfy numerous goals, which are nowadays a tough compromise of economics (operator's interest) and quality criteria of delivered energy (buyers' interest).

The process of achieving those development goals must include all subjects of the open electricity market in a fair, unbiased and transparent manner.

In order to successfully perform their responsibilities in planning, operating, managing and maintaining the distribution networks, engineers and technicians need a sound knowledge of new technologies. The challenge for tertiary education providers is to match the curricula and syllabi with the new demands of electric energy industry and open market.

The subject "Distribution and industrial networks" is designed for the vocational specialist Year 4 students of the electric power study programme at the Higher Education Technical School of Vocational Studies in Novi Sad (VTSNS), Serbia. The aim of the subject is to familiarize students with both traditional and new technologies in electric power networks and equip them with skills in planning, exploitation and management of modern distribution and industrial networks.

In accordance with the Bologna Declaration, the subject lasts one semester, has 3+3 hours of theory and tutorials per week, and is worth 8 ECTS. The pre-exam assessment contains a closed-book test and a project assignment - written and orally presented in front of the class. The final assessment is written, consisting of solving predominantly numerical problems.

The syllabus consists of 12 modules, covering the following: electric power system structure, level of electrification, network planning concepts, consumer connection types, measurement and tariffing systems, network protection, distribution management system, regulative issues in Serbia, and techno-economic aspects of network development. Integration aspects of distributed generation (renewable and non-renewable) into the distribution network are covered by the subject, entitled “Small generation plants and renewable energy sources“.

The teaching material is compiled from several books and scripts [1]-[10], related author papers [11]-[15], technical manuals of Serbian Electric Power Distribution Company [16]-[18], EU and Serbian standards, legal documents of the Serbian Ministry of Power [19], as well as the notes from lectures and tutorials.

II. Syllabus

In the following chapters, the subject modules are shortly presented and discussed, in order to illustrate the breadth, complexity and multidisciplinary nature of modern power distribution networks.

A. Power Sector in Serbia

The introductory module deals with basic aspects of organization of the electric energy sector in the world, EU, neighbouring countries and Serbia. Emphasis is placed on the deregulation of the electric sector, implemented from the 1990s in some countries and from 2004 in Serbia. The aim is to convey the key issues of deregulation through the fundamental conditions necessary for the implementation of the open market:

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- accessible network with public tariffs,
- market exchange of electric energy,
- existence of a licensed operator which manages the energy balance, and
- charging of electric energy.

The students get familiarized with the basic principles of deregulation:

- A special regulatory authority, which supervises the electric energy market, must be formed;
- Network operation/management must be legally separated from both generation and sales of electric energy, and is characterised by:
  - network company must have a concession/licence,
  - network company has a duty to:
    - connect consumers on reasonable terms,
    - deliver electric energy to all consumers,
    - measures and reports the delivered energy; and
- Network tariffs must be determined in a reasonable way and must not depend on the consumer's distance.

Next, this module presents the basic features and elements of the electric distribution system in Serbia, consisting of low-voltage (0.42 kV) network, medium-voltage (10 kV, 20 kV and 35 kV) network and a part of 110 kV network. These include transformer stations (TS), switchgear, telecommunication system, information system (ICT) and other infrastructure necessary for operation.

Taking the electricity from the transmission system and distributing it, as the fundamental technical activity of a distribution company, is supported by a number of operative activities. The students get familiar with the most important activities of the power distribution such as:

- control, maintenance and planning of the power distribution network,
- maintenance of measurement technology and measurement points,
- measuring and periodical reading of the consumed electric energy,
- forming the periodical calculations (bills), and
- billing the consumers.

B. Categories of Consumers and Simultaneity Factor

This module is devoted to consumer types and their categorization, according to the electrification level and simultaneity factor. The terms of the electric energy supplier and consumer are defined in the *Act on terms for delivery of electric energy*. Consumers (buyers) are all users whose objects, facilities or installations are connected to the provider's network.

The criteria and norms for determining the consumer categories and groups of consumers are defined by the *Tariff system,* determined on the basis of:

- voltage on the delivery point, V_n,
- simultaneity power of a consumer, P_j,
- purpose of the consumption,
- type of measurement devices and measurement method, and
- the other criteria defined in the *Tariff system*.

According to the voltage level on delivery point, the following consumer categories are defined in Serbia:

- Consumption at the high voltage, $V_n \geq 110$ kV;
- Consumption at the medium voltage, $1\text{kV} \leq V_n \leq 110$ kV,
- Consumption at the low voltage, $V_n \leq 1$kV.

The course then discusses partial, full and total types of electrification for household areas. For instance, partial electrification is when a household has access to electric energy, hot water and gas.

The students get familiar with the simultaneity factor j_n, which is important for understanding the functioning and planning of distributive system and industrial facilities. The simultaneity factor is defined as the ratio of the total peak power and the sum of individual peak powers of n consumers:

$$j_n = \frac{P_{\Sigma vn}}{\sum_i^n P_{vi}} \tag{1}$$

If the peak consumption of one household is assumed to follow a *Gaussian* probability distribution, the *Rusk's* formula [3] is valid for the simultaneity factor of n households:

$$j_n = j_\infty + \frac{1 - j_\infty}{\sqrt{n}} \tag{2}$$

where j_∞ is the simultaneity factor for an infinite number of households.

This module then discusses and analyses load profiles of electric consumptions, loading factor and losses factor. The aim is that the students comprehend the changing needs of electricity consumers during the day, the week and the season.

C. Network Planning

This module familiarizes students with concepts of development of both low-voltage and medium-voltage networks and appropriate transformer stations in urban, suburban and rural areas, as well as in industry, as in Fig. 1. The most important requirements to be considered when deciding on distribution system concepts are discussed in [1], [3], and [4] as:

- safety level,
- quality of delivered electric energy,
- economic aspects,
- good integration into the existing system,
- simplicity,
- flexibility, evolutiveness and adaptability, and
- controllability.

Students are introduced to system planning, exploitation and management as the main tasks of electric power distribution. Key tasks in system planning and exploitation are various technical analyses: reliability (planning stage), safety (exploitation), and economic viability of different solutions, analyses of consumption, equipment, protection, and conceptual configuration of medium and low voltage networks.

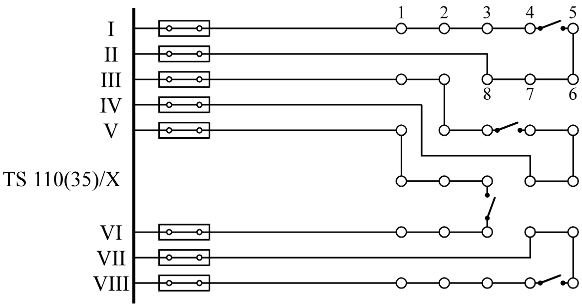

Fig. 1 Network with open loops' concept

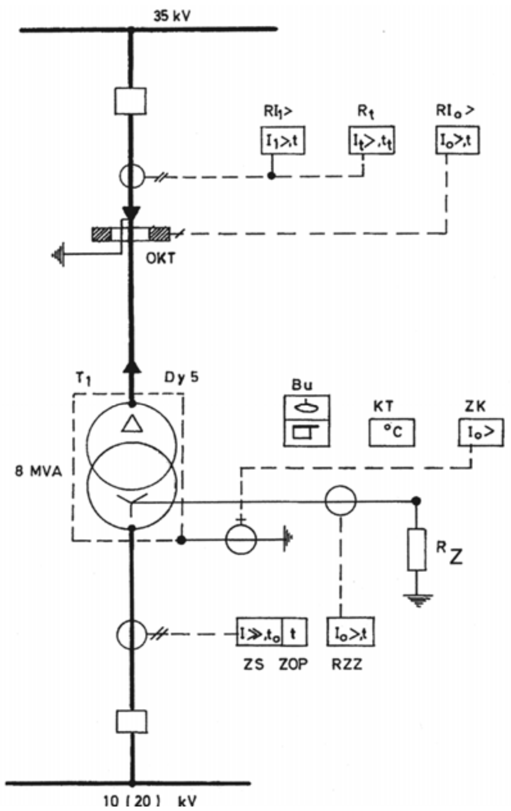

Fig. 2 Transformer protection in TS 35/10.5 kV/kV

D. Consumers' Connection on the Network

In this module the students are familiarized with basic features and technical solutions of connecting the consumers to the electric network, including [3]:

- consumer premises,
- consumer's electro energetic object (connection, measurement box, vertical distribution to the units, switchbox in the unit),
- the connection point (the place of connecting the consumer's electric objects with the low-voltage network),
- connection lines, outer connection, internal connection, etc.

E. Network Protection

In this module, the students acquire the basics of relay protection of distribution and industrial networks. Relay protection is a set of automated devices that serve to protect the power system elements and are essential for its normal and reliable operation.

Today, digital relays, representing the third generation of protective device resulting from the development of microprocessor and computer techniques have the dominant role in the power system protection.

The course discusses the following line and substation (HV/MV, MV/LV) protection [4]:

- Short circuit and over-current protection of LV and MV lines,
- Ground-fault protection of MV line,
- Short circuit protection of 10 kV(20 kV) bus in TS 110/10(20) kV/kV,
- Short-circuit transformer protection 10(20)/0.42 kV/kV,
- *Buholtz* transformer protection,
- Ground-fault and reserve protection of TS HV/MV and TS MV/MV, as in Fig. 2, and
- Overloading transformer protection.

Especially this module deals with different conceptions of transformer HV/MV neutral grounding and grounding impact on the applied type of protection [2], [3].

In this module, the students learn the basic characteristics of measuring and auxiliary devices and in particular the current and voltage transformer ratio, accuracy class, over-current number, and error of measurement transformers, as well as accuracy class of electric meters.

G. Power Quality

In this module, the students learn the meaning of the concepts of continuity of supply and power quality as well as the obligations of the supplier.

The supplier is obliged to supply consumers permanently and continuously with electricity of appropriate quality, under conditions determined by the *Energy Law*, the *General Conditions for the Delivery of Electric Power* and the contract. Interruptions of supply arising from the operation of the protection device are not considered as the intermittent power supply.

The obligation of the supplier to supply consumers with quality electricity means that power supply must be of the nominal voltage and frequency.

Allowed deviations of the rated voltage are as follows [3]:

- From - 10% up to + 10% on the 110 kV, 35 kV, 20 kV and 10 kV voltage level; and
- From - 10% up to + 5% on the 230 V voltage level.

Allowed values of frequency deviation are in the range:

- (50+0.1) Hz,
- (50+0.2) Hz in case of short system disturbance; and
- (50-0.5) Hz in the exceptional case of system disturbance, with the deviation not longer than 15 minutes.

If there is no possibility of backup supply from another electric power facility, the power supply may be temporarily suspended i.e. restricted in the following cases: faults, revision, overhaul or reconstruction of power facility, works on the accession of new consumers, or vis major. In addition, the students learn basics of power quality standards, types and sources of disturbance in distribution and industrial grid such as voltage drop, voltage dip, harmonics, unbalance, flickers etc., as well as measures to minimize it.

H. Techno-Economic Analysis

This module deals with the economic aspects of the construction and operation of distribution networks such as [3], [6]-[9]:

- investment, maintenance and annual costs of distribution networks,
- actualization rate (interest rate, amortization, losses),
- the net present value of the investment, and
- internal rate of return on investment.

I. Distribution Management System

In this module, the students learn basics of Distribution Management System (DMS) which is a key to achieving energy efficiency in modern power distribution systems [15]. Distribution Management System is usually based on several types of applications. Applications which prepare data for starting the other power applications are Network Model, Topology Analyser, and Load Estimation. Applications for network analysis are used for estimation of distribution system state indices, like: Power Flow, Fault Calculation, Reliability Analysis, and Performance Indices. Power Flow is used for calculation of stationary load flow and voltage profile in radial and weakly meshed distribution networks. There are modules for single-phase power flow for balanced and three-phase un-balanced loading. Application is based on efficient compensation based power flow algorithm. Fault Calculation is used for calculations of stationary regimes in the distribution network after the fault. Application is based on efficient hybrid compensation algorithm for distribution short circuit analysis and theory of symmetrical components.

One of the main functional calculations of the distribution network is Network Reconfiguration, which is used for determination of the optimal network configuration regarding the considered criterion.

The most sophisticated calculation in distribution network analysis is Fault Management, which consists of three sub-applications: Fault Location and Isolation, Supply Restoration, and Large Area Supply Restoration.

J. Regulations

The theme of this module is the valid legal regulations in the field of distribution of electricity in the Republic of Serbia. Distribution system operator was introduced in Serbia and the Energy Agency was founded by the Energy Law, which came into force in July 2004. Distribution System Operator has established the Rules of Distribution System Operation [16]. Management and provision of the operational readiness of power distribution system are determined by these rules. In addition, these rules determine:

- Technical conditions for connecting users to the system,
- Technical requirements for the safe operation of the distribution system,
- Conditions for the provision of reliable and continuous delivery of electricity to customers,
- Emergency procedures,
- Rules on the third party access to the distribution system,
- Functional requirements and measuring devices,
- The method of electricity measurement, etc.

Activity of electricity distribution falls under another act of legislation - the *Law on Metrology*. Besides, for electricity distribution companies, two documents are essential: *Act of conditions for the electricity supply* and the *Tariff system*, i.e. price list for the sale of electricity.

III. Evaluation of Educational Outcomes

In accordance with Bologna Declaration, the subject lasts one semester, has 3+3 hours of theory and tutorials per week, and is worth 8 ECTS. The pre-exam assessment contains a closed-book test and a project assignment - written and orally presented in front of the class.

The themes of the project assignment, which can be from any chapter of the syllabus, are chosen by the students. The aim of the project assignment is to promote students creativity, critical thinking and problem–solving skills. The final assessment is written, consisting of solving predominantly numerical problems.

The results of evaluation of educational outcomes of 90 students on the subject, since being introduced five years ago, are presented in Tables I and II.

It is encouraging to notice the consistency in overall achieved marks, which are in good agreement with the average achievement of the Year 4 students in the VTSNS as a whole. It should be noticed that the majority of the specialist students are employed.

The first two cohorts seem to have done better in assignments, but the explanation is simple – 18.75% of students in 2014/15 cohort have had intense commitments at their current work place. The reduced time they could commit to the assignments had an impact on the assignment quality and therefore resulted in notably lower marks, bringing the average assignment mark to only 81%. These students also failed to appear on the final exam in both first and second sittings. On the other hand, the final tests of other students were better than average, reaching 92%.

The overall mark on the subject (84.3-89.4) shows a stable increase in last five years, except in the 2015/2016 school year, which could be explained by the intense commitments of the students at their current work places.

IV. Conclusion

Distribution of electric power has always been an interdisciplinary topic. In recent decades, it has become more complex due to influences of deregulation and distributed renewable generation, as well as integration of both power electronics and ICT.

Compiling a modern syllabus in the area of distribution and industrial networks is a challenge for the lecturers in higher education in Serbia. This is especially true for the vocational stream of higher education (higher technical colleges), where a specialist engineer is expected to acquire not only a solid theoretical knowledge but also a wide range of practical field skills to be applied in the electric power industry.

TABLE I
AVERAGE MARK OF ASSESSED COMPONENTS

%	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017
In-class test (theory)	71.0	74.2	68.3	68.1	70.2
Assignment	92.0	90.7	81.0	85.4	84.7
Final test (numerical)	84.6	86.1	92.3	89.1	92.4
Overall mark	86.5	84.3	87.1	79.7	89.4

TABLE II
SUCCESS OF COMPLETION OF THE WHOLE SUBJECT

%	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017
First sitting	83.3	60.0	50.0	50.0	60.0
Second sitting	16.7	35.0	31.3	32.0	26.7
Third sitting	-	5.0	18.7	18.0	13.3

The results of evaluation of educational outcomes show a satisfactory level of passing exams on the subject since being introduced five years ago. Besides, experience shows positive students' feedback as well as employers' satisfaction regarding the acquired knowledge and skills necessary for planning, exploitation and management of distribution and industrial power networks in the open electricity market.

It is notable that the project assignment, the component which bonds the theoretical and practical issues of the syllabus, is the part in which they showed great initiative and commitment, got best marks and also enjoyed most. It is very important conclusion having in mind wide spread lack of students' enthusiasm for attending the lectures at higher education institutions.

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