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Educational Plan and Program of the Subject Maintenance of Electric Power Equipment

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***Abstract*—**Students of Higher Education Technical School of Professional Studies in Novi Sad follow the subject 'Maintenance of Electric Power Equipment' at the Electrotechnical Department. This paper presents educational plan and program of the subject Maintenance of Electric Power Equipment. The course deals with the problems of preventive and investing maintenance of transformer stations (TS), performing and maintenance of grounding of TS and pillars, as well as tracing and detection the location of the cables failure. There is a special elaborated subject concerning the safe work conditions for the electrician during network maintenance, as well as the basics of making and keeping technical documentation of the equipment.

***Keywords*—**Educational plan and program, electric power equipment, maintenance, technical documentation, safe work.

I. Introduction

SAFE and quality supplying with electrical energy represents a fundamental request posted to power systems by the users. Condition of the high voltage equipment in a distribution substation has considerable influence on the functional reliability of electric power systems. Maintenance of electric power equipment in contemporary power systems is of crucial importance.

The issue of maintenance of electric power equipment is especially broad, complex and multidisciplinary.

Apart from many titles in the area of maintenance of electric power equipment, it is very hard to find a text-book profound enough to include all subjects in maintenance of the all voltage equipment and, on the other side, concise, detailed and practical to make acquired knowledge applicable in practical work.

Students of third grade at the Higher Education Technical School of Professional Studies, Electrotechnical Department, in Novi Sad, follow the subject 'Maintenance of Electric Power Equipment'.

The subject is designed as half-yearly and according to the Bologna Declaration it contributes 6 ESPB points. It covers three classes of lecture and two classes of exercises a week, in total of 75 classes per course.

The precondition for following this subject is adopted knowledge and passing the exam from the subject 'Basics of Electrotechnics 1', 'Basics of Electrotechnics 2', as well as 'Production and Transmission of Electrical Energy'.

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In this paper educational plan and program for the subject 'Maintenance of Electric Power Equipment' is presented. Material and examples with comments are collected from many text-books and miscellany examples for practice, Technical recommendations by Electric Power Distribution of Serbia (EPS), instructions of *Elektrovojvodina* Novi Sad, as well as from lectures and exercises practicing at the Higher Education Technical School of Professional studies in Novi Sad.

II. Preventive and Investing Maintenance

Through the module 'Preventive and investing maintenance' students gain knowledge about basic concepts and definitions from the field maintenance of electric power objects. The course begins with definition of concepts:

- Maintenance of an object is work by which it is possible to ensure technically right condition of an object. It may be preventive (revision, repairing work and field tests) and investing (reconstruction),
- Revision represents periodical review of electric power objects for evaluating their conditions and electric capability,
- Repairing work represents work aiming to maintain the object in technically right condition, in a frame of needs of power plant, by repairs and changes of worn-out parts,
- Investing maintenance consists from big repairs and changes of the basic means with the aim to maintain electric power objects in technical right condition,
- Current maintenance makes repairs of a lesser or bigger damages on the power plant objects.

There is a special processed checklist for each TS during preventive maintaining, and it applies on the construction and electromontage part. As far as electromontage part of TS is concerned, all elements of the plant are processed in a special way, that is [1]:

- power transformer,
- switches,
- circuit breakers (disconnectors),
- electrical power and voltage measuring transformers,
- supporting and conductive insulators,
- supervoltage arrestors,
- capacitor batteries,
- bus bars,
- unidirectional current sources,
- switchboards, desks and lockers,
- compressor stations,
- measuring and protective devices,
- earthing system.

Revision, power plant checking and repairing work on the large equipment in TS are set up as a special procedure, and there is a special note about their periodicity.

III. Switching Operations:

Manipulations of the switching apparatus, switches and disconnectors present the most dangerous tasks during maintenance of electric power equipment. Repairing work of the plant elements is not practically feasible without turning off certain parts of the plant which is also impossible without manipulations of the switches and disconnectors. The experience has shown that human factor is predominant in damages caused by manipulations with the switching apparatus. It is the main reason why we are so focused on the manipulations module during the course.

This module is intended to provide students an introductory understanding of characteristics and functions of switching equipment, configuration of different types of TS 110/x kV and TS 35/x kV, as well as training of students for executing of manipulations with switching equipment.

Complete thematic units of this module are:

- Introducing the substation TS 110/x kV and TS 35/x kV via presentation 'The substation walkthrough',
- The switch functions (turning-on and turning-off of drive currents and failure current),
- Function of circuit breaker (disconnector) (it obviously breaks part of switchgear),
- Function of switch-disconnector (turning on failure current and drive current and turning off drive current),
- Outgoing cell and elements:
  - bus bars
  - bus bars disconnector
  - switch
  - outgoing disconnector, and
  - disconnector for grounding
- Types of switchboard system [1]:
  - one bus bar system
  - system with one bus bar and bypass disconnector,
  - system with a main and auxiliary bus bar and by pass disconnector
  - system with two systems of main bus bars and one transformer
  - system with two systems of main bus bars and two transformer
- Sequence of manipulations:
  - during turning-off of the switch,
  - during turning-on the switch,
  - during load shedding from main to auxiliary bus bars,
  - during load shedding from one to another transformer,
  - during activation of two parallel transformers, and
  - during repair of transformer.
- Blockades:
  - incomplete (blockade of by-pass disconnector while switch is open)
  - complete (blockade of by-pass disconnector when disconnector of trafo field is open)

For the purpose of performance of this module there is a special interactive application for exercising the manipulation, as presented on Fig. 1.

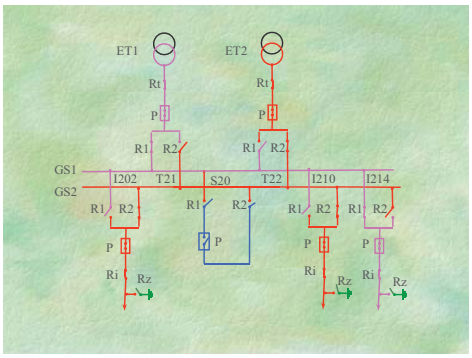

Fig. 1 Fitted scheme of TS 110/x kV for exercising of manipulations

During each of the manipulations there is analysis of possible mistakes which are the cause of the accidents. Experience showed that students accepted interactive work on exercises very well. Although they altogether participated in the exercises, there was an individual request from each of them – to bring decision alone.

IV. Functional Testing of TS 110/X kV

Before activation of any electric power object, it is necessary to research its functionality and check if the object has been done according to appropriate projects, if the measuring-protective devices and other equipment are inbuilt and finally, if the complete object functions on projected way. Module 'Functional testing of new TS 110/x kV' is divided on a few phases:

- visual checking of equipment,
- testing of 'large equipment' (electrical and voltage measuring transformers, switches etc.),
- testing of connections between conductors and circuit branches of auxiliary tensions,
- testing of 'secondary equipment' (measuring and protective devices)
- testing of the automatics,
- testing of the signaling.

Substation is secured with the local automatics with a special task to perform anticipated manipulations which in that way secure functioning of TS without interruption in power supply, that is to say, with short interruptions. This module deals with testing of following automatics 20 kV:

- automatically repeated turn-on switch (APU),
- automatically turn-on of shaft-coupling and load shedding of transformer AUSRET,
- break-down of parallel operation of transformer,
- transformer switch break-of on 20 kV at definite break-off of switch on 110 kV,
- automatic turn-on and turn-of switch for cooling of the transformer,
- outer and inner heating,

- automatic turn-on of an emergency light,

As well as automatics on 110 kV side:

- automatically repeated turn-on switch (APU),
- repeated automatically turn-on of shaft coupling and transformer PAUSIT,
- asymmetry of poles and
- automatic voltage regulation.

In order to understand automatics functioning, there is a brief explanation of basic and back-up protection of transformer 110/x kV [1].

V. Thermovision Testing

In this module, students get insight into basic concepts, equipment and methods for thermovision of electric power objects. Thermographic controls belong to a group of preventive testing which detects malfunctions manifested in higher temperature caused by heating. Controls are applied for all connecting elements, cable sheath, extensions and expansion coupling, contact and connecting places within switch, measuring and power transformer, extensions and joints on electric long distance lines, and that photographed from earth and from the air (from helicopter).

Module 'Thermovision testing' is dealing with following thematic units [2]:

- electromagnetic spectrum of radiation,
- absolute blackbody,
- blackbody emissivity,
- *Planck*'s law,
- hot place,
- overtemperature,
- infrared camera,
- termographic snapshot, and
- criteria for assessment of equipment condition.

By using thermographic snapshots of transformer's elements on exercises, it is possible for students to notice hot places like potential places of faults. It also allows students to express and analyze misapprehension as a possible result of the testing method for equipment with gas SF6. Fig. 2 represents thermographic snapshot of the power measuring transformer 110 kV.

There is analysis of method-comparison study of the transformer elements in all three phases, as well as a method of circuit tracking in one phase. Also, there is a special testing of switches and disconnectors, that is to say, measuring of the open contact resistance as additional method when thermovision picture is not sufficient for finding the potential break-down.

Faults are classified according established criteria based on recommendations, and regulations and based on long term acquired experience.

VI. Substation Grounding

Important aspect of maintenance of electric power equipment is performing and maintenance of TS grounding. Through the module 'Performing and maintenance of TS grounding', students get valuable insight into following phenomena and concepts [3]-[7]:

- influence of electrical power on human body,
- electrical resistance of human body,
- distribution of potential,
- touch and step voltage,
- characteristic measures of grounding,
- specific ground resistivity,
- horizontal and vertical groundings,
- types of grounding: hemisphere, plate, rod, flat band,
- resistance of the grounding expansion,
- considering multilayer quality of a ground during calculation resistivity of grounding,
- good praxis during grounding process, and
- influence of cables and safety cords on resistivity of system grounding.

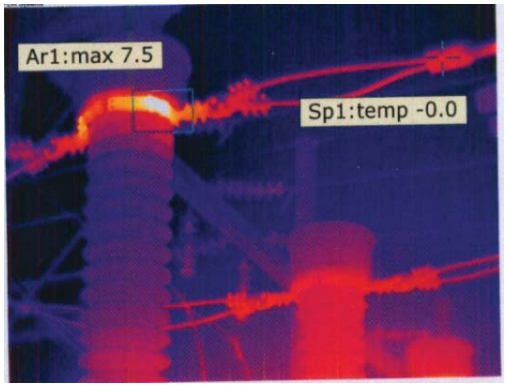

Fig. 2 Termographic snapshot of the current measuring transformer 110 kV

The important method units in this module are allowed touch and step voltage. Besides, students get familiar with UI method for measuring the resistance of TS 110/x kV grounding system, as well as a type of measuring and calculation of touch and step voltage in TS.

VII. Maintenance of Cable Lines

One of the most specific tasks during maintenance of electric power equipment is surely maintenance of underground cable lines. Through the module 'Maintenance of underground lines', students are getting insight into the construction and electromontage part of underground lines, that is:

- cable route,
- culvert and pipes,
- cable shafts,
- cable junction cabinet and cable junction boxes,
- cable line,
- cable endings,
- cable connectors,
- overvoltage arrestors.

The most difficult task is certainly detection of the exact location of the fault on underground line. This module deals with methods, measuring equipment and procedures for:

- cable identification,
- determining of the cable route (routing),
- revealing of the exact place of fault on the underground line.

Locating the place of fault requires introducing of the students with concepts such as: characteristic impedance of cable, rate of the cable wave and relative dielectric cable constant.

Within the course there is elaboration of following types of fault:

- faults on isolation with or without contact with earth,
- interruptions or serial faults, different by resistance value,
- jumps,
- short-circuits,
- perturbation in impedance of cable, and
- fault on a mantle.

Students are getting insight into the phases during the process of searching the location of fault:

- identifying of the fault and determining the type of the fault,
- short or long transformation of the fault,
- prelocation of the fault, and
- micro-location of fault.

Within the course we elaborate locating of the place of fault by the method of reflection of waves.

Students get insight into the contemporary measuring equipment, procedures and appearance of monitor on the instruments for identifying of fault at typical and nontypical faults of cable line. Snapshot of the impulse sequence given by current-impulse method of the fault prelocation is shown in Fig. 3. The analysis of examples from the praxis is pointed out during exercises.

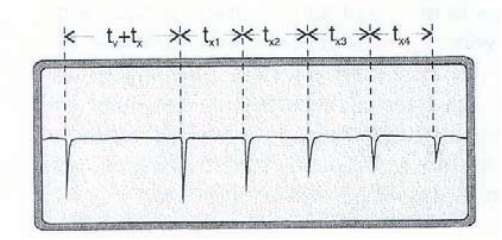

Fig. 3 Snapshot of the impulse sequence given by the Current Impulse Method of fault prelocation

VIII. Maintenance Of Overhead Lines

Through the module 'Maintenance of overhead lines', there is a special elaboration of construction and electromontage part of overhead lines [8]:

- pillars (wooden, concrete, iron),
- roof and wall holders and console,
- conductors and protective cords,
- insulators and insulator chains,
- pole disconnectors,
- routing of lines,
- grounding of pillars.

The most important plant testing of overhead lines applies on measuring the pillar grounding. In this module, the problems of performing protective pillar grounding 110 kV, 35 kV, 20 kV, 10 kV, and 0.4 kV are especially pointed out. Students get insight into the following concepts:

- the pillar grounding,
- earth connection,
- collecting earth connection,
- grounding resistance,
- pillar grounding impedance,
- striking resistance of grounding,
- touch voltage,
- voltage before touch,
- human body electrical resistance.

The students get familiar with criteria for dimensioning of protective pillar grounding:

- criterion of feedback jump during lightning stroke to a pillar,
- criterion of protection from touch voltage.

There is elaboration about typical pillar groundings (ring and radial). On the exercises, students resolve simple tasks with typical grounding with real number values from distribution network operation.

There is explanation of the role of protective conductor in medium voltage overhead lines, as well as work grounding in low voltage overhead line.

IX. Safe Work

The module 'Safe working conditions of the electrician and manipulators during maintenance of electric power objects' is of crucial importance [9]. This module is intended for the student to become aware of the fact that electric current is 'goods as any other', but with distinction that electric current 'can kill' [10], [11]. For mastering the matter from this field, apart from general literature and law regulations, we use internal standards by *Elektrovojvodina Novi Sad:*

- regulations about safety and health protection on work,
- regulations about technical measures of safety work conditions at work in electroenergetic objects, and
- set of instructions for safe work.

In this module, we elaborate activities undertaken toward safety work conditions on maintenance of overhead line and cable network voltage 10 kV, 20 kV and 35 kV, TS 35/10 kV/kV, TS 20/0.4 kV and TS 10/0.4 kV/kV.

The subject that is elaborated in detail and supported by practical exercises represents 'five gold rules', which applies on every operator before beginning with work on maintenance of electric power equipment, by established order:

1. turning-off the power (visible interruption),
2. preventing of accidentally repeated turning-on,
3. determining of condition without voltage,
4. grounding and shorting, and
5. enclosing from parts under voltage.

Additional protection measures during work on low voltage, as well as special requirements in relation to grounding and shorting represent special focus of the program.

X. Technical Documentation

The module 'Technical documentation' is intended for students to gain knowledge about creating, keeping and reading of technical documentation. Maintenance of electric power equipment is performed according to the technical regulation which includes:

- standards,
- technical rules,
- branch and internal standards,
- technical recommendations and instructions.

Students gain further knowledge about types of projects such as:

- general project,
- preliminary project,
- main project,
- execution project,
- as-built drawings.

Further, the course deals with detailed description of conditions for connecting objects to the network, including issuing of electric power permit. Further, students get knowledge about documentation on maintenance, including:

- book of maintenance,
- log with event on object,
- exam protocol and attests,
- card catalogs,
- records about maintenance.

XI. Conclusion

Contemporary maintenance of electric power equipment is based on professional and qualified crews for maintenance, application of modern devices for diagnostics and monitoring, in strict compliance with procedures required by quality system, application of technical database and software, but also to a great extent on skills and experience of operators.

Creation of educational plan and program for the field maintenance of electric power equipment is a challenge for the academic people. This especially applies on higher education technical schools of professional studies because of high expectations from professional engineer regarding his theoretical knowledge, but also his practical knowledge and skills applicable in power industry.

Accordingly, the plan and program of the subject 'Maintenance of Electric Power Equipment' should be created in accordance to good praxis and requirements of contemporary electric power distribution in conditions of open electricity market.

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