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Janusz Mindykowski
Department of Ship Electrical Power Engineering
Gdynia Maritime Academy, Poland
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USE OF THE SHIP'S ELECTRICAL POWER STATION SIMULATORS FOR IMPROVING EMERGENCY PREPAREDNESS OF STUDENTS AND ENGINE ROOM OFFICERS

The main focus of this paper is concentrated on the use of physical and virtual models, of ship's electrical power plant generally called simulators, to improve emergency preparedness of trainees, i.e. students and engine room officers. The ship's electrical power station plays a vital role in the operation process of the ship. An appropriate quality of the electrical energy produced, sent and used the basic requirement for correct running of all ship's technical systems, and for some of the IMO instruments, e.g. SOLAS convention call on regulations related to this matter. Starting with these requirements, a short description of the used simulators has been given. Further on, the framework of learning program and training possibilities have been described. Taking into consideration the chosen examples, among other in appropriate distribution of active and reactive power between generating sets working in parallel and worsening the electrical energy quality caused by damage of harmonic filter co-operated with shaft generators, the consequences like emergency situations will be shown. Some conclusions and proposals will be formulated to avoid such dangers and, first of all, to pay attention to such situations during the educational process.

1. INTRODUCTION

The ship's electrical power station plays a vital role in the operations process of the ship and appropriate quality of the electrical energy produced, sent and used is the basic requirement for correct running of all ship technical systems [1]. Almost every failure of ship systems such as propulsion or navigation carries the risk of a ship disaster being at the same time a threat to human life and the environment.

The voltage and frequency deviations, distortions and voltage asymmetry may cause not only a treat to safe operation of the ship's technical system but also an additional energy loss and the decrease of ship's electrical equipment durability especially electrical machines and related apparatus, e.g. elements connected with lighting and signalling [1]. It is worth stressing that electrical motors installed in the ship's electrical system have to operate in unparalleled in land electrical engineering conditions. Generally, motors in the considered system are supplied with distorted asymmetric voltage of a considerably changing frequency and the rms value causes summing up the different additional energy loss.

Another problem is the necessity for free standing generating sets to work in parallel [1], [2]. For safety reasons, it is necessary to maintain power surplus as a rule; it is 20% power of a single generator while at regular sailing or greater when manoeuvring. This brings some economic consequences in the form of the specific fuel consumption increase by a diesel engine and the necessity of parallel work of generating sets. But the importance of proportionate load distribution plays a vital role just during manoeuvring, in difficult weather and navigational conditions. The results of disproportionate load distribution between generating sets working in parallel is, first of all, an apparent overload of one of the generators when there is still some power margin left. As a result of current or active power overload of one of the generators when the others are not fully loaded, the disconnecting system which switches off the less important loads starts operating (Meyer's system) and when the load increases the overloaded generator is switched of automatically by the main switch. In a situation when power surplus of the remaining generators does not suffice to take over the load of the turned off generator power supply disppears in the whole electrical power network, which can cause serious consequences connected with the safe operation of a ship [1], [2].

2. IMO INSTRUMENTS RELATED TO THE VITAL ROLE OF ELECTRICAL EQUIPMENT

The wording "IMO instruments" [3], [4], [5], [6] covers conventions and protocols accepted by the Governments of the Parties, which ratified them. In short, the principal purpose of the instruments developed under the auspices of the United Nations International Maritime Organisation (IMO) is to develop regulations to enhance the safety of international shipping. Additional aims, i.e. pollution prevention and liability and compensation for maritime claims are also included in the IMO's list of responsibilities [4], [7]. Some of its most important mandatory legal instruments, essentially international treaties, are SOLAS [8]– International Convention for Safety of Life and Sea, MARPOL – International Convention for the Prevention of Ship Pollution, COLREGS – Convention on the International Regulations for Preventing Collisions at Sea, 1972 and STCW 1978 as amended in 1995 [1], [9], [10] – International Convention on Standards of Training, Certification and Watchkeeping for Seafarers.

Except for the above mentioned conventions there are other "IMO instruments" of different character – numerous protocols, resolutions, guidance and circulars, which should be considered and respected.

Electrical, Electronic and Control Engineering in STCW' 95

There are many electrical installations of items of electronic equipment so vital that the safety of life at sea would be at risk if those installations or items of equipment failed, especially:

- main and emergency generators and power distribution system

- engine room alarm and automatic control system
- main engine control system
- steam plant control system
- manual and automatic ship steering
- gyro compass and repeaters
- internal ship communication systems
- fire detecting and alarm systems
- windlass control systems

The new training and qualifications requirements based on STCW' 95 convention are taken into consideration and introduced in the above mentioned aspects in the related chapter III, [1], [4], [6], [10] under the function "Electrical, electronic and control engineering", at the operational and management level, respectively.

In appropriate tables of the cited IMO instrument, the competence, the range of knowledge, understanding and proficiency, as well as methods for demonstrating competence and finally criteria for evaluating competence are presented [1], [4].

Electrical installations in SOLAS

In SOLAS Consolidated Edition, 1997 [8] we can note a special attention paid to electrical installations.

Regulation 40 of Part D [8] refers to all electrical installations of the ship in normal operational and habitable conditions as well as under various emergency conditions. Additionally, safety of passengers, crew and ship from electrical hazards is mentioned.

The next Regulation 41 is devoted to the main source of electrical poser and lighting systems. The capacity of configuration of the main source is determined. Moreover, some detailed requirements concerning each of the generating sets under emergency situations, are formulated for instance "the remaining generating sets shall be capable of providing the electrical services necessary to start the main propulsion plant from a dead ship condition" (42.1.4).

Also the requirements, when the emergency source of electrical power may be used for the purpose of starting from a dead ship condition are presented in the above mentioned paragraph. The paragraphs 42.2, 42.3 and 42.4 describe requirements for main and emergency electric lighting system, main switchboard and main busbars, where the total installed electrical power of the main generating sets in excess of 3MW, respectively.

Regulation 42 determines emergency source of electrical power in passenger ships. This emergency source of electrical power is defined under the assumption that, "the electrical power available shall be sufficient to supply all those services that are essential for safety in an emergency, due regard being paid to such services that may have to be operated simultaneously" (42.2).

Further on, some detailed requirements referring to the given period of time (36 hours or half an hour) and given type of emergency source of electrical power (generator or accumulator battery) are formulated. Another subparagraph is devoted to supplementary emergency lighting for ro-ro passenger ship.

Regulation 43, is similar to regulation 42, and describes the requirements for emergency source of electrical power in cargo ships.

Due to safety reasons very important issues are included in Regulation 44, concerning starting arrangements for emergency generating sets. The last Regulation 45 in Part D of Chapter II-1 of SOLAS [8] in connected with precautions against shock, fire and other hazards of electrical origin. To summarize, Part D by referring to electrical installations of the ship describes constructional and operational conditions and it also formulates detailed requirements for this equipment, especially paying attention to emergency situations.

3. IMPROVING EMERGENCY PREPAREDNESS OF TRAINEES OF ENGINE ROOM DEPARTMENT REGARDING ELECTRICAL POWER STATION OPERATION

In accordance with STCW'95 amended convention, the group of accepted methods for demonstrating competence, which consists, among others, of "approved simulator training, where appropriate" and "approved laboratory equipment training" [1], [4].

The main focus of the this paper is concentrated on the use of physical and virtual models [6], [9], and on the use of ship's electrical power plant generally called simulators, to improve emergency preparedness of trainees. Basing the curriculum on this equipment and specialized learning program the trainees have possibilities to upgrade their fundamental knowledge concerning the ship electrical power plant, to develop operation skills and to train to refresh their reactions to emergency situations.

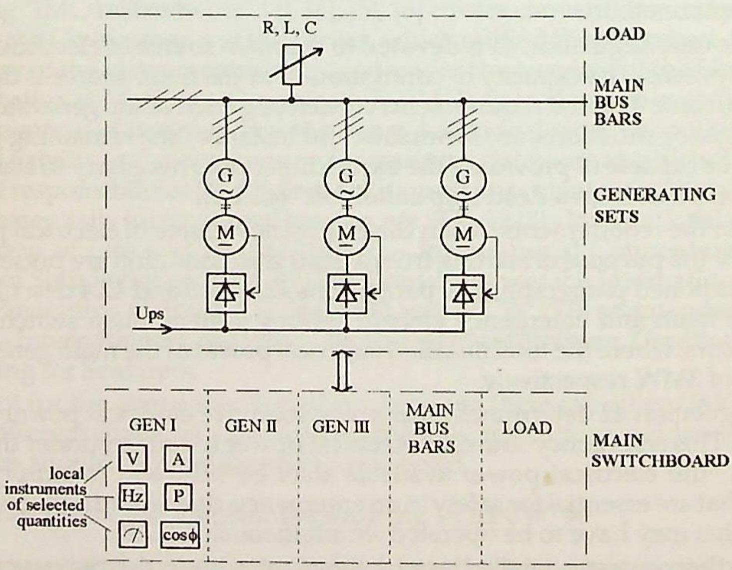

Figure 1. Physical model of ship electrical power plant

Simulator of ship's electrical power plant

Physical model

In the educational process of engineers, who serve as officers of marine engine rooms, a physical model of ship electrical power plant is used (Figure 1) [9]. This model consists of three generating sets in which the diesel drive of synchronized generators has been replaced by adequately controlled DC motors, of different character and of adjustable load and main switch board. A presented configuration will be soon developed by shaft generator inclusion.

The elaborated model of the ship's electrical power plant is based in the first place on a realistic hardware layer since the purpose of classes is to make students and course participants familiar with the physical aspect of the phenomena connected with the ship's electrical power plant running.

Virtual model

In order to widen didactic functions and make students work more by themselves this model can be coupled with a virtual measuring system. According to one of the most frequently used definitions, taken from National Instruments [11]:

"Virtual Instrument is a layer of software and/or hardware added to a general-purpose computer in such a fashion that users can interact with the computer as though it were their own custom-designed traditional electronic instrument". Another version of the definition is: "industry-standard computers equipped with the company's user-friendly application software, cost-effective hardware and driver software that together perform the functions of traditional instruments".

According to Hewlett-Packard conception [11], the capability of using graphical software and a personal computer for processing and displaying measurement results has been referred to as "virtual instrumentation".

This therm can be used to describe the following four areas [9], [11]:

- An Instrument System as a Virtual Instrument (VI)
- Software Graphical Panel as a VI
- Graphical Programming Technique as a VI
- Reconfigurable Building Blocks as a VI

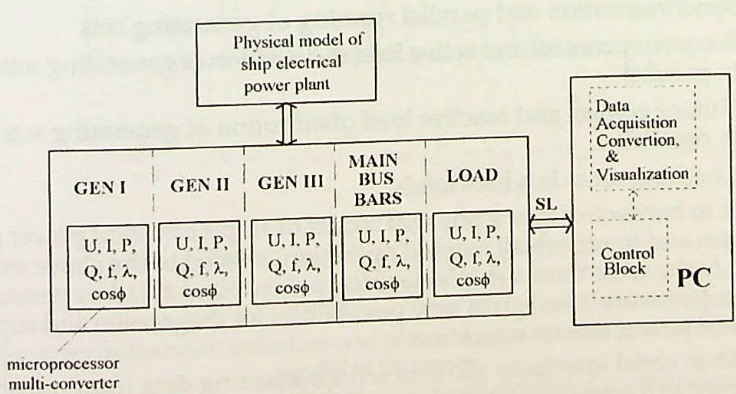

Figure 2. Ship electrical power plant aided by virtual measurement system

More details about all the above mentioned areas describing "virtual instrument" may be found in [9], [11]. It is worth noting, that the considered "virtual instrument" is in fact a very wide term, but finally main defined functions of VI software are: D/D conversion and data presentation.

Figure 2 presents hardware structure of virtual system [9] for measuring selected operational parameters of a ship's electrical power plant, that is voltages, current, power, frequency, cos j and power factor with the use of original multi-functional measuring instruments [12] made by the Department of Ship Electrical Power Engineering of Gdynia Maritime Academy.

Measuring data are taken from multi-transducers installed in selected components of the electrical power engineering system. At present, a software involving the virtual measuring system for didactic needs is being tested.

Learning program and training possibilities for improving emergency preparedness.

Learning program is based on the syllabus of studies for the specialization of "Ship Electro-automation" leading to engine room officers diplomas, particularly oriented at eletrical engineering matters which in Polandare Called marine electrician officers. This syllabus covers 35 subjects amounting to 3890 hours at Academy and 9 months of sea practice. Full content of the syllabus was circulated at the 30th of STW Sub-committee session as the Appendix to the document "Education, training and certification of Marine Electrician Officers in Poland" [13]. The use of simulators is especially recommended for subjects: ship electrical equipment, ship electrical power generation and distribution, ship automatic control systems, marine propulsion systems and auxiliary machinery and technical operation and diagnostics of ship electrical equipment.

The simulators presented in part 3.1 of this paper give wide possibilities for improving emergency preparedness of trainees, in the context of SOLAS requirements [8] for ship electrical power station operation. The following functions of ship electrical power plant are accomplished during classes:

- Starting generating set
- Synchronization and parallel running of generating sets
- Frequency control and active load distribution of generating sets working in parallel
- Voltage control and reactive load distribution of generating sets working in parallel
- Checking main bus bars loads

Due to hardware layer a physical model of ship's electrical power plant enables to train and to refresh all manual operations related to the above mentioned functions. At the same time, a ship's electrical power plant aided by measuring virtual system (software layer) gives new possibilities for diagnostics and supervising the electrical power station operation.

Built-in serial interfaces allow to send measuring data from transducers to the computer and controlling signals from the computer to transducers. Software tools installed in a computer offer a number of possibilities to use measuring results, often impossible to carry out in multi-transducers sets themselves [9]:

- analysis in output signals of measuring transducers in the virtual system enables to obtain more, practically any processed, measuring information in comparison to the conventional method,
- graphic presentation of the selected data in 2D or 3D on the screen, what enables to link causes and effects concerning operation of the specified elements of a ship electrical power plant,
- simple determination of the required energy quality rating produced and used in a ship electrical power engineering system,
- registration of the selected values according to the program determined by a system user and trend analysis of their changes in the function of given variables, among others in 2D or 3D.

All these properties may be extremely useful for improving emergency preparedness of trainees.

4. EXEMPLARY EMERGENCY SITUATIONS, THE CONSEQUENCES AND PREVENTIVE MEASURES

Improper distribution of active and reactive power between generating sets working in parallel.

In order to determine the correctness of active and reactive power distribution between generators we needed the indications specified by measuring instruments of the Main Switchboard. The best solution is a set which consists of kilowatt-meter and kvar-meter for each generator.

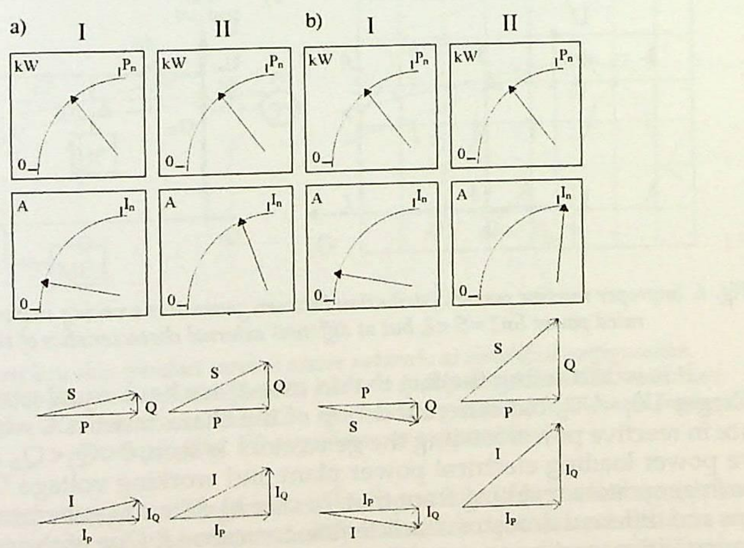

Fig. 3. Measuring instruments' indications and phasor diagrams for two generators working in parallel in the case of:
a) uniform active power distribution and unequal distributed reactive power
b) uniform active power distribution and extremely incorrect reactive power distribution (generator I gives up capacitive reactive power)

Monitoring of the generator's active and reactive loading can be carried out simultaneously. Also, we can use a single meter with the possibility to switch from active power measurement to reactive and vice versa.

If there is no kvar-meter the improper reactive power distribution between generators working parallely is difficult to spot.

In order to determine the reactive power distribution it is necessary to introduce parallely working generators into a state of proportional active power loading. It means that if there were two generators of equal rated power then we would get identical indications of kilowattmeters. The improper reactive power distribution would be revealed by different indications of ammeters measuring the apparent current but not the active one.

Exemplary measuring instruments' indications would be in the effect of such reactive power distribution as shown in Fig. 3 [2].

Fig. 3b illustrates extremely incorrect reactive power distribution. Ammeter of generator II indicates its overload at substantial margin of active power which could yet be applied to that generator. Moreover, the generator, being current-overloaded, will be switched off by the master switch of Mayer's protective system will operate, and that will happen without any real overload of electric power plant (i.e., at its apparent overload). Related characteristics U = f (Q) of corresponding cases presented in Figure 3, when the generators' characteristics do not coincide the reactive power distribution proceeds, for instance, in the way shown in Fig. 4.

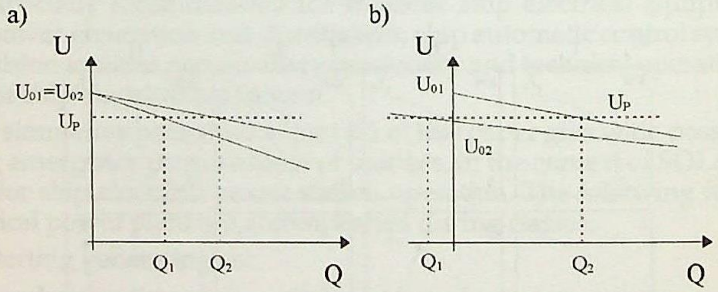

Fig. 4. Improper reactive power distribution between generators working in parallel, of the same rated power Sn1=S n2, but at different external characteristics of them 2

It is worth roting the fact that in case a) we have equal generator idle run voltages $U0_1=U0_2$, but different droop of the characteristics U=f(Q). The difference in reactive power loading the generators is seen, $0<Q_1<Q_2$, at a given reactive power loading electrical power plant and working voltage U0 identical for booth generators resulting from that. In case b) different generator idle run voltages and different droop of characteristic correspond. One of the generators gives the capacitive reactive power of $Q_1<0$ back to the electrical network, the other – the inductive reactive power of $Q_2>0$.

Reactive power distribution would be correct if at variable reactive power load in ship's electric network excitation currents of the generators changed in the same way. Therefore external characteristics U = f(Q) of equal rated power generators have to coincide and to effect correct reactive power distribution this way.

In order to improve this situation, generally, the crucial step is to draw external characteristics of booth generators to a common point, i.e. to level idle run voltage to the same value $U0_1 = U0_2$ [2]. Proper active power distribution (set e.g. by hand) is a condition for correction to reactive power distribution especially when kVar-meter is not installed and ammeters indications of parallelly working generators are the only sources of data on improper reactive power distribution. The last step in reactive power correction is setting external characteristics droops to be identical with the use of the related potentiometer for reactive power distribution control. The correction procedure is the same for different types of field regulators and it may be very easily adapted to the training program with the use of virtual model of the ship's electrical power plant.

Worsening of electrical energy quality caused by failure of harmonic filter co-operated with shaft generator

This case concerns the ship power station equipped with shaft generator and semiconductor converter with appropriate passive harmonic filter for limiting disturbance influence. In reality, one of the capacitors was damaged. In consequence, the asymmetry, distorted voltage waveform (Fig. 5) has been registered on the bus bars of the ship switchboard. This waveform was taken by analogous oscilloscope during the normal, rut conditions of ship operation [14], [15].

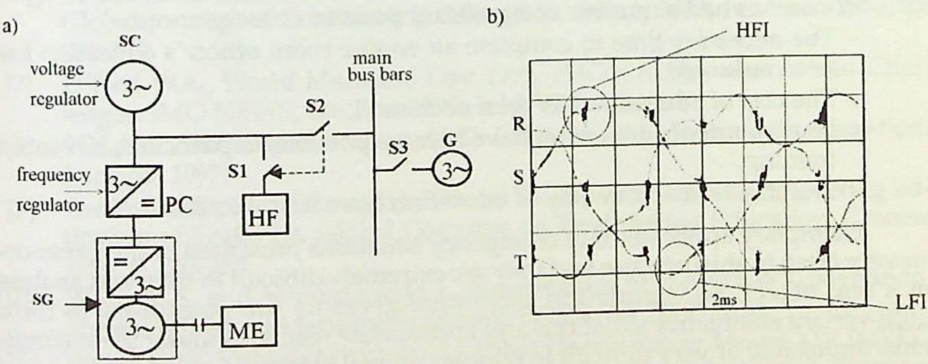

Fig. 5. Exemplary ship (product carrier) power network: a) simplified configuration b) exemplary three-phase voltage waveform on bus bars of ship switchboard: S1 – switches, SG – shaft generator, PC – power converter, SG – synchronous generator, ME – main engine, HF – harmonic filter, SC – synchronous compensator

Considered voltage oscillograms make it possible enle to distinguish both kinds of interferences, which independently influence devices and systems supplied by ship's electrical power network. Low-frequency interferences (LFI), result from harmonic filter failure and high-frequency interferences (HFI), caused by commutation processes. Registered causes of failures concerned, among others, total hazard (accidental) switching-off of satellite communication system (GMDSS), have a vital role for safe ship operation. The failures were reported by radio to the appropriate technical services in different ports, where damages of the system were not confirmed and detected. The reason for this situation was the fact that the port ship's electrical power system is fed only by classical generating sets and then shaft generator is out of work. Under these conditions correct diagnosis in the considered range is practically impossible and previously reported to repair devices under new conditions of supplying work correctly. The cited event is not an exception and consequences of these situations have a negative influence on watchkeeping as well as on treating safety of life at sea as on wide problem.

Preventive measure for such situations would be an application of specialized electrical power analyser [14], [16] for monitoring harmonic as well high-frequency interferences, independently from each phase. This problem seems to be important because of the rapid saturation by highly advanced electronic systems for new-built ships as well as for modernization needs concerning the existing ships, e.g. based on microprocessor controllers. A general observation may be formulated, that in many situations we can not forecast future failures, especially in the context of electrical installations operation.

CONCLUSION

One of the most important factors determining the emergency preparedness of trainees in the course of educational process is the use of simulators. Some IMO instruments, for instance STCW'95 and SOLAS conventions had a new impact on the related undertakings. The introduction of simulators into the education of engine room officers has had a number of significant positive consequences:

- The necessary time to complete an engine room officer's education has been reduced,
- The cost of education has been decreased,
- New spheres of education have become possible, in particular, advanced training,
- The standard and quality of education have been increased.

Exemplary applications of emergency situations presented in the paper occur very often in ship practice and they are extremely difficult to train and analyse on a real object. So, simulation technique gives us the possibility to train multi-variant emergency situations and appropriate reactions under these conditions, impossible or very difficult to educate on real objects.

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Sažetak

UPOTREBA SIMULATORA BRODSKOGA ELEKTRIČNOG POSTROJENJA KAKO BI SE POBOLJŠALA SPREMNOST STUDENATA I STROJARSKIH ČASNIKA DA DJELUJU U SLUČAJU OPASNOSTI

U ovom se radu središnja pažnja posvećuje korištenju stvarnih i pravih modela brodskoga električnog postrojenja koji se nazivaju simulatorima, u svrhu poboljšanja spremnosti studenata i časnika stroja da djeluju u slučaju opasnosti.
Brodsko električno postrojenje od vitalne je važnosti u radnom procesu broda. Prava kvaliteta proizvedene, odašiljane i upotrijebljene električne energije osnovni je zahtjev koji se mora ispuniti želimo li da svi tehnički sustavi na brodu ispravno rade. Neki se pravilnici IMO-a, poput primjerice SOLAS-konvencije, pozivaju na propise koji se na to odnose.
Počevši od tih zahtjeva, dan je i kratak opisi korištenih simulatora. Opisani su i okvirni nastavni programi, a prikazane su i mogućnosti stručnog osposobljavanja. Uzevši u obzir odabrane uzorke, između ostaloga u pravilnoj raspodjeli aktivne i reaktivne energije između agregata u paralelnom radu i lošije kvalitete električne energije uzrokovane oštećenjima harmonijskog filtera i osovinskih generatora zajedno, prikazat će se i posljedica toga, kao što su one u slučajevima opasnosti. Izložit će se neki zaključci i dati prijedlozi za izbjegavanje takvih opasnosti i, kao prvo, predložit će se način kako obratiti pažnju takvim situacijama u nastavnom procesu.