GOCE DELCEV UNIVERSITY, SHTIP, NORTH MACEDONIA

FACULTY OF ELECTRICAL ENGINEERING

ETIMA 2021

FIRST INTERNATIONAL CONFERENCE

19-21 OCTOBER, 2021

TECHNICAL SCIENCES APPLIED IN ECONOMY, EDUCATION AND INDUSTRY

УНИВЕРЗИТЕТ „ГОЦЕ ДЕЛЧЕВ” - ШТИП
ЕЛЕКТРОТЕХНИЧКИ ФАКУЛТЕТ

UNIVERSITY „GOCE DELCHEV” - SHTIP
FACULTY OF ELECTRICAL ENGINEERING

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FIRST INTERNATIONAL CONFERENCE

ЕТИМА / ETIMA 2021

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19-21 Октомври 2021| 19-21 October 2021

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CIP - Каталогизација во публикација
Национална и универзитетска библиотека "Св. Климент Охридски", Скопје

62-049.8(062)
004-049.8(062)

МЕЃУНАРОДНА конференција ЕТИМА (1 ; 2021)
Зборник на трудови [Електронски извор] / Прва меѓународна конференција ЕТИМА 2021, 19-21 Октомври 2021 = Conference proceedings / First international conferece ETIMA 2021, 19-21 October 2021 ; [главен и одговорен уредник Сашо Гелев]. - Штип: Универзитет "Гоце Делчев", Електротехнички факултет = Shtip: University "Goce Delchev", Faculty of Electrical Engineering, 2021

Начин на пристапување (URL): https://js.ugd.edu.mk/index.php/etima. - Текст во PDF формат, содржи 358 стр.илустр. - Наслов преземен од екранот. - Опис на изворот на ден 15.10.2021. - Трудови на мак. и англ. јазик. - Библиографија кон трудовите

ISBN 978-608-244-823-7

1. Напор. ств. насл.
а) Електротехника -- Примена -- Собири б) Машинство -- Примена -- Собири
в) Автоматика -- Примена -- Собири г) Информатика -- Примена -- Собири

COBISS.MK-ID 55209989

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PREFACE

The Faculty of Electrical Engineering at University Goce Delcev (UGD), has organized the International Conference ***Electrical Engineering, Informatics, Machinery and Automation - Technical Sciences applied in Economy, Education and Industry-ETIMA.***
ETIMA has a goal to gather the scientists, professors, experts and professionals from the field of technical sciences in one place as a forum for exchange of ideas, to strengthen the multidisciplinary research and cooperation and to promote the achievements of technology and its impact on every aspect of living. We hope that this conference will continue to be a venue for presenting the latest research results and developments on the field of technology.
Conference ETIMA was held as online conference where contributed more than sixty colleagues, from six different countries with forty papers.
We would like to express our gratitude to all the colleagues, who contributed to the success of ETIMA'21 by presenting the results of their current research activities and by launching the new ideas through many fruitful discussions.
We invite you and your colleagues also to attend ETIMA Conference in the future. One should believe that next time we will have opportunity to meet each other and exchange ideas, scientific knowledge and useful information in direct contact, as well as to enjoy the social events together.

The Organizing Committee of the Conference

ПРЕДГОВОР

Меѓународната конференција ***Електротехника, Технологија, Информатика, Машинство и Автоматика-технички науки во служба на економија, образование и индустрија-ЕТИМА*** е организирана од страна на Електротехничкиот факултет при Универзитетот Гоце Делчев.
ЕТИМА има за цел да ги собере на едно место научниците, професорите, експертите и професионалците од полето на техничките науки и да претставува форум за размена на идеи, да го зајканува мултидисциплинарното истражување и соработка и да ги промовира технолошките достигнувања и нивното влијание врз секој аспект од живеењето. Се надеваме дека оваа конференција ќе продолжи да биде настан на кој ќе се презентираат најновите резултати од истражувањата и развојот на полето на технологијата.
Конференцијата ЕТИМА се одржа online и на неа дадоа свој допринос повеќе од шеесет автори од шест различни земји со четириесет труда.
Сакаме да ја искажеме нашата благодарност до сите колеги кои допринесоа за успехот на ЕТИМА'21 со презентирање на резултати од нивните тековни истражувања и со лансирање на нови идеи преку многу плодни дискусии.

Ве покануваме Вие и Вашите колеги да земете учество на ЕТИМА и во иднина. Веруваме дека следниот пат ќе имаме можност да се сретнеме, да размениме идеи, знаење и корисни информации во директен контакт, но исто така да уживаме заедно и во друштвените настани.

Организационен одбор на конференцијата

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UDC: 621.316.5.072.8

IMPACT OF FAULTS IN TRANSMISSION AND DISTRIBUTION NETWORK ON VOLTAGE SAGS

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Abstract
This article deals with the issue of evaluation of voltage sags based on the analysis of the impact of different fault types in power systems. The aim is to identify a range of influences of considered faults on voltage sags in the industrial low voltage network. The analysis is based on the simulation calculation of selected faults to classify negative effects causing potential improper operation of industry equipment due to faults in the power system. In the paper are also described options of proposed measures for minimization of these phenomena.

Key words
Short-circuit, earth fault, voltage sag, industrial network, distribution system, simulation.

Introduction
In general, electrical appliances are dependent on the power supply, mainly on actual voltage magnitude in the electric network. Voltage sags or interruptions in the power supply could result in a negative influence on the operation of appliances. The appliance's ability to withstand voltage sag, respectively outage depends on the internal structure and topology of electrical appliances. [5], [7]
The electric network provides in the context of measures for the protection of sensitive customers' equipment very limited possibilities. The duration of voltage sags and short-term interruptions can be reduced by increasing the capacity of the loop of power lines or improved realization of elements of power system; the depth of voltage sags can be reduced by increasing the short-circuit power of supply network. [7], [8]
Most voltage sags and short-term interruptions are caused by short circuits or earth faults occurring in the power supply. These failures cannot be eliminated, but the number can be significantly reduced. Restriction of the number of short-circuits results in less negative impact on electrical appliances and can be achieved by, e.g. improved realization of elements of the power system, replacing the overhead lines in cable lines, cleaning insulators, as more consistent and more frequent elements controls of the supply network, etc. [5], [7]
Malfunctioning equipment on a large scale in industrial enterprises can have significant economic impacts on their operation. Such facts may ultimately lead to e.g. to change the electricity supplier or other changes, but the origin of the problems may be based on the electrical topology, the specific location of the company in this topology. [1], [2]
The following research is based on this assumption, where the aim is to assess the impact of various faults in the transmission and distribution electrical networks on the voltage conditions in the distribution of an industrial enterprise. The range of the impact of selected faults will be identified by quantifying voltage sags that could cause malfunction of industrial equipment such as inverters, etc.
A suitable tool for an assessment of voltage conditions in the industrial network is a simulation analysis of various faults in the power system.

The research is performed on a mathematical model based on the real topology of a part of the transmission and distribution system with all devices, which is complemented by a detailed topology of the industrial power system.

1. Literature review

In recent years, the increase of automation in the industrial sector has brought problems with power quality. These problems are mainly associated with using of electronic control circuits, e.g. production technology sensitive to voltage sags. These devices are an important part of the production and their failure can result in production restriction for a long time and cause significant technological and financial losses for consumer. [1], [2], [4]

Overvoltage, voltage sags and interruptions are usually the reason of the faults in electrical networks. Unpredictable load change or production change could cause the any voltage deviations. It is not possible to eliminate all transient events in power system, and thus it is not possible to maintain the constant value of voltage in low voltage networks. Despite, producers should ensure that their products are able to withstand the operation within the defined limits. [3], [5]

Another point of view, the distribution system operators should keep the power quality according to standard EN 50160 "Voltage characteristics of electricity supplied by public electricity networks. In practice, it often happens that the distribution system operators comply with the power quality requirements, but sensitive equipment installed at the customer do not have to work properly. It is not possible to guarantee permanently constant value of voltage in the distribution system due to various sources causing these sags. And therefore, sensitive equipment should be capable to withstand the voltage changes in exactly defined limits in terms of depth and duration of the voltage sag. [6], [8]

To analyze the range of voltage sags, there were modeled a part of high and medium voltage network. Both models were created based on the real data of distribution and industrial network regarding simulation of the impact of different fault types in distribution network on the low voltage level.

Based on the simulation calculations, there are analysed potential causations of voltage sags with appropriate measures proposed for elimination of these phenomena in the industrial low voltage network.

2. Model description

Voltage sags assessment in industrial network is based on the simulation calculations for different types of faults (short circuits and earth faults) in the power system at different voltage levels.

In the first part, assessment of voltage sags in industrial network is performed using a model of HV distribution network (110kV) according to Fig.1. This area is supplied via a transformer 400kV/110kV, nominal power 350MVA, short-circuit power in that node is 5.5GVA. Transmission power system is modeled using a model of equivalent network with given short-circuit power.

In the second part, assessment of voltage sags in industrial network is performed using a model of MV distribution network (22kV) according to Fig.2. This area is supplied via transformers T1.1 and T1.2 (T1.2 je turned off, both busbars in present substation are supplied from transformer T1.1).

Present models are based on real data of power system included given values of consumption, i.e. topology of high (HV) and medium voltage (MV) level, transformers parameters, types and lengths power lines and cables, loads.

3. Simulation scenarios

Analysis and impact of considered faults on the voltage conditions (voltage sags) in industrial network are performed for the following simulation scenarios:

- Line-to-line short-circuit, line-to-line short-circuit with earth connection and line-to-earth short-circuit in the transmission network near the transformer 400kV/110kV,
- Three-phase short-circuit, line-to-line short-circuit, line-to-line short-circuit with earth connection and line-to-earth short-circuit in HV network (110kV),
- 1st earth fault at different locations in MV network (22kV),
- 1st earth fault and following 2nd earth fault at different locations in MV network (22kV).

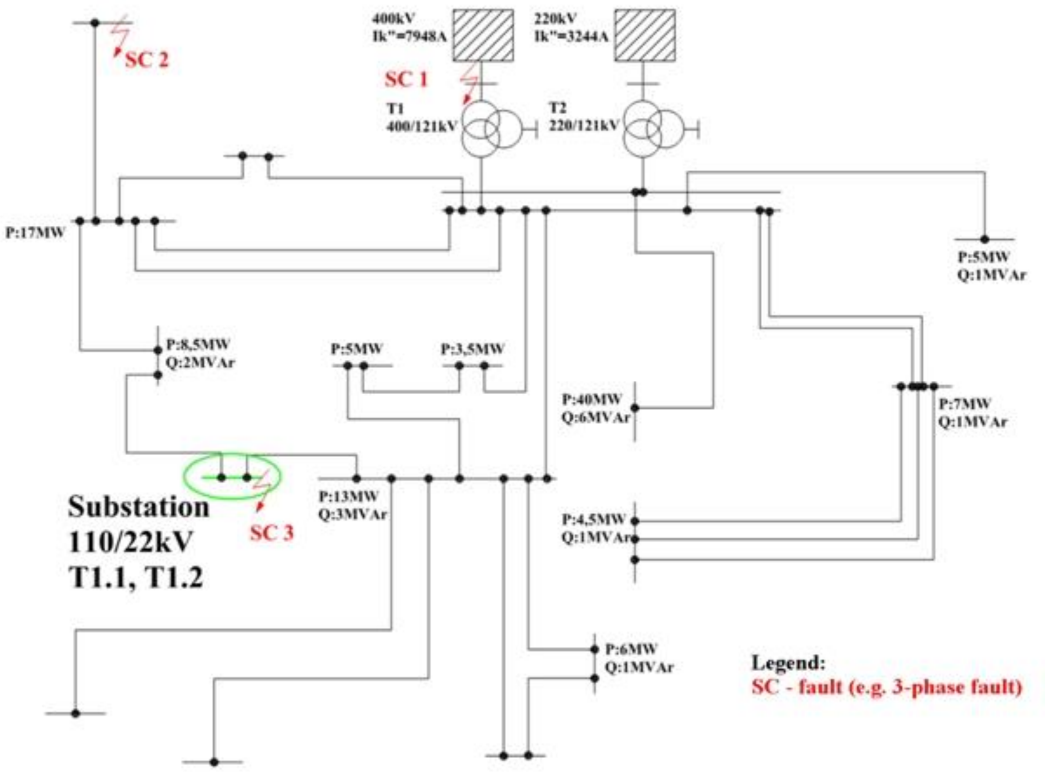


Fig. 1 Simplified model of HV distribution network

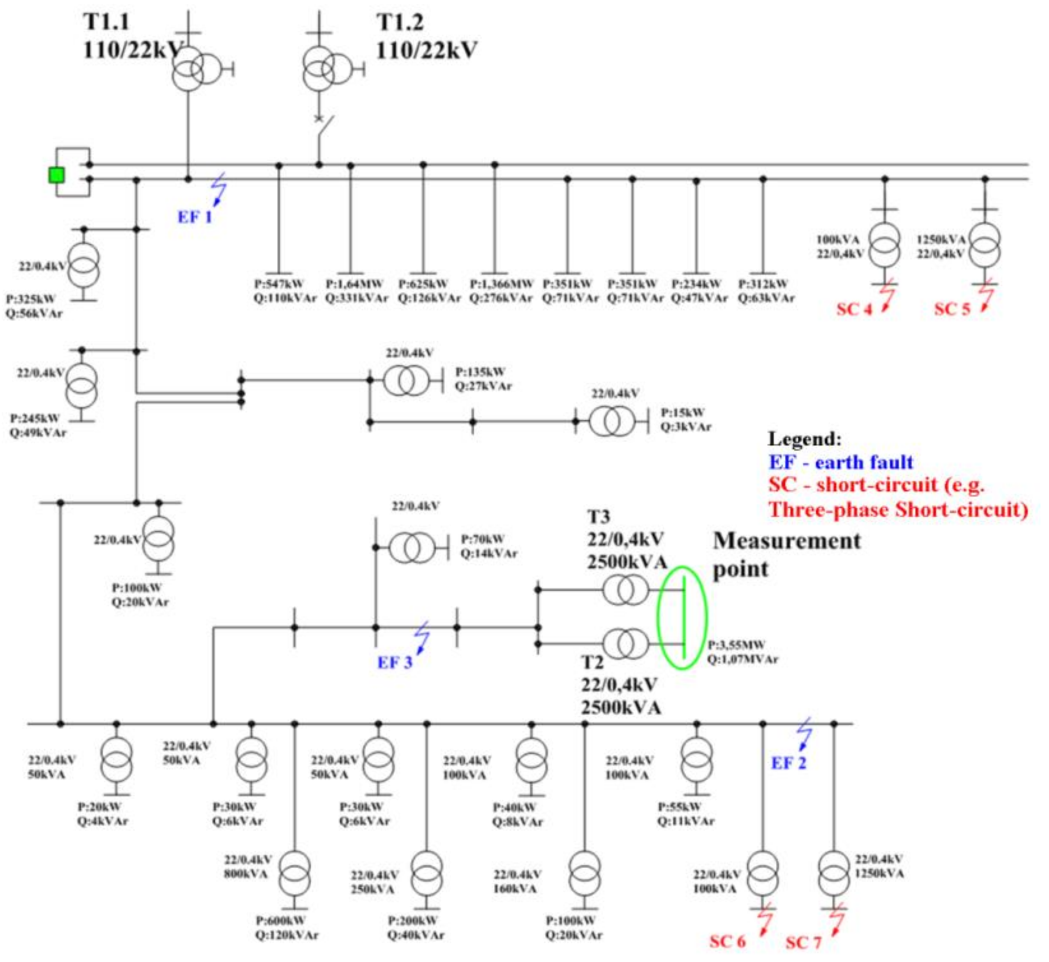


Fig. 2 Simplified model of MV distribution network

Table 1 Simulation scenarios list

Voltage level	**Fault type**	**Fault position**
400kV	Line-to-earth short-circuit, Line-to-line short-circuit, Line-to-line short-circuit with earth connection	SC1
110kV	Line-to-earth short-circuit, Line-to-line short-circuit, Line-to-line short-circuit with earth connection, Three-phase short-circuit	SC2
	Line-to-earth short-circuit with the resistance of 100Ω	SC2
	Line-to-earth short-circuit, Line-to-line short-circuit, Line-to-line short-circuit with earth connection	SC3
22kV	1st earth fault with following 2nd earth fault in the same substation	EF1
	1st earth fault with following 2nd earth fault in the same substation	EF2
	1st earth fault with following 2nd earth fault in the same substation	EF3
	1st earth fault with following 2nd earth fault in another substation	EF1-EF2
	1st earth fault with following 2nd earth fault in another substation	EF1-EF3
	1st earth fault with following 2nd earth fault in another substation	EF2-EF3
0.4kV	Line-to-earth short-circuit, Line-to-line short-circuit, Line-to-line short-circuit with earth connection, Three-phase short-circuit (transformer with ratio 22kV/0.4kV and nominal power of 100kVA)	SC7
	Three-phase short-circuit (transformer with ratio 22kV/0.4kV and nominal power of 100kVA)	SC6

	Three-phase short-circuit (transformer with ratio 22kV/0.4kV and nominal power of 1250kVA)	SC5
	Three-phase short-circuit (transformer with ratio 22kV/0.4kV and nominal power of 100kVA)	SC4

All considered faults were performed as zero-resistance faults except one case of simulation of line-to-earth short-circuit with fault resistance (100Ω) in HV network (110kV).

Simulated scenarios in MV network (22kV) were performed for the 1st earth fault and following the 2nd earth fault in the same substation and also for the 1st earth fault and following the 2nd earth fault in another substation.

Fault in LV network (0.4kV) (Fig. 2 – SC6) were performed on the secondary side of transformer 22kV/0.4kV with small and large nominal power.

Selection of fault locations were determined in order to identify an impact significance of near, far and earth faults on voltage sags in the assessed low voltage (LV) network (0.4kV) in the industry.

Simulation experiment is assessed separately based on the results of simulation calculations in power system as follows:

- HV network (110kV) supplied from transformer T1 400kV/110kV and transformer T2 220kV/110kV;
- MV network (22kV) supplied from transformers 110kV/22kV T1.1 and T1.2;
- Transformers 22kV/0.4kV T1 and T2 with measurement of phase voltage at LV side of transformer.

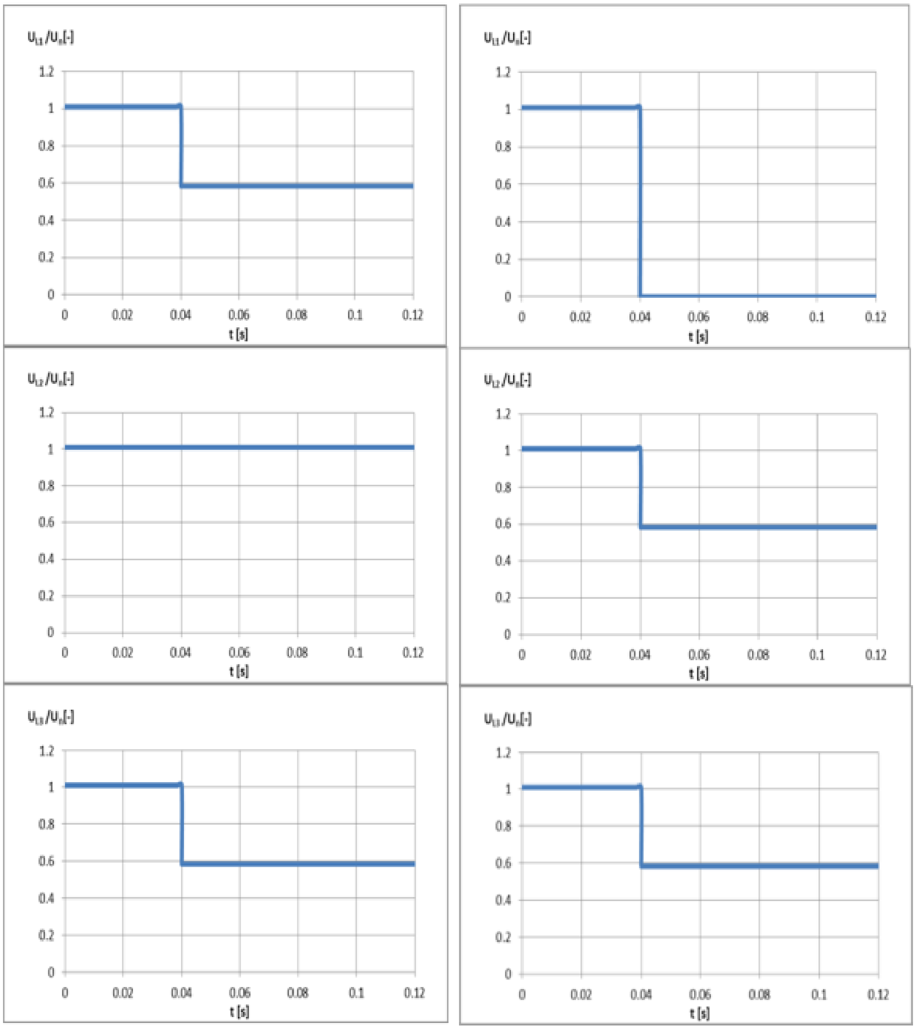
4. Simulation results

The aim of simulation scenarios is to evaluate of voltage on MV and LV side of transformer T2 and T3 and to assess an impact on possible voltage sags. Therefore, on LV side the values of phase voltages are evaluated: absolute voltage change, percentage voltage changes related to nominal voltage (230V). On MV side the values of phase-to-phase voltages are evaluated.

4.1 Line-to-earth Short-circuit and Line-to-line Short-circuit with Earth Connection in Transmission Network

Faults located in the transmission network were simulated on the busbar of primary transformer side T1 400kV/110kV. In the following figures are shown occurred phase voltage sags in LV network for cases: line-to-earth short-circuit, and line-to-line short-circuit with earth connection (fault location in Fig.1- SC1).

From the voltage waveforms, it results that fault in the transmission network near to the transformer 400kV/110kV has a significant impact on the voltage sag in LV voltage network. In case of the line-to-line short-circuit with earth connection the voltage in phase L1 dropped in LV network to the zero value. Due to power supply HV network (110kV) from the only one transformer (T1 400kV/110kV), faults near to the transformer significantly affect the voltage conditions in HV and thus in LV network.



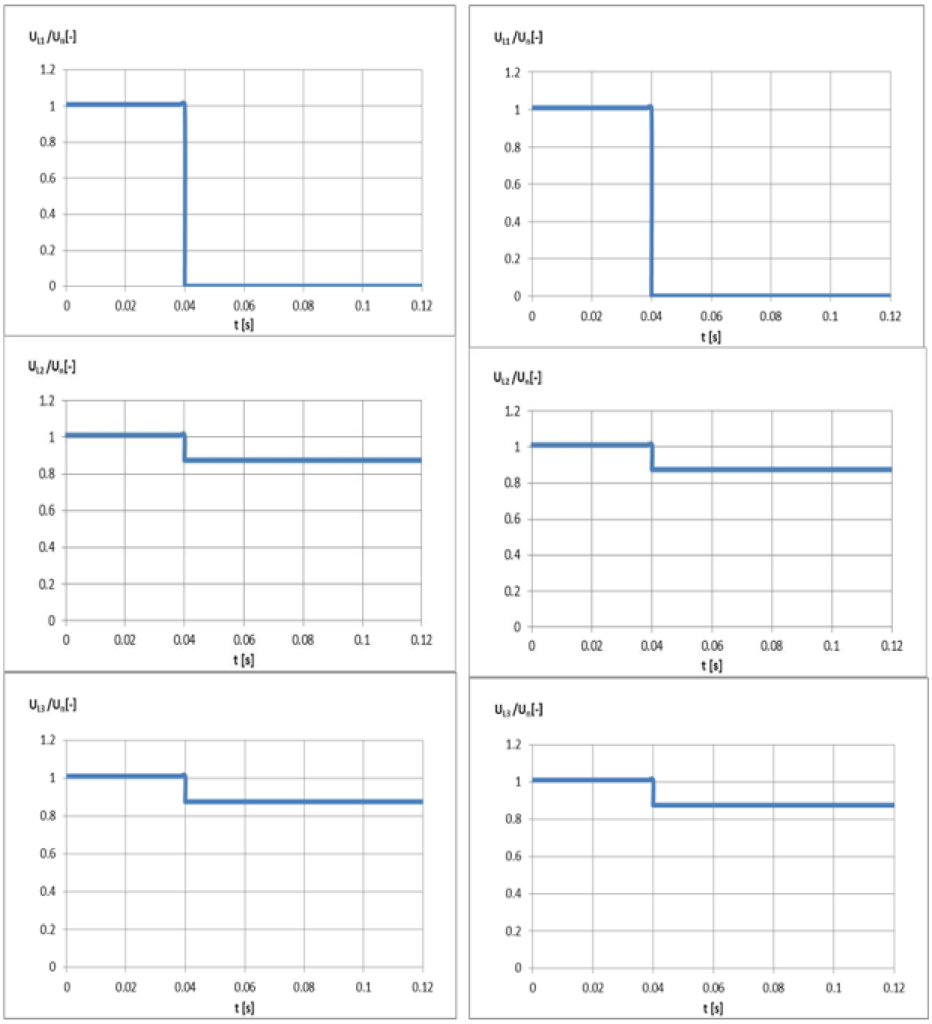
a) **b)**

Fig. 3 a) Phase voltage (p.u.) in LV network for case: line-to-earth short-circuit in transmission network, b) Phase voltage (p.u.) in LV network for case: line-to-line short-circuit with earth connection in transmission network

4.2 Line-to-line Short-circuit and Line-to-line Short-circuit with Earth Connection in 110kV Network near to Transformer 110kV/22kV

This simulation scenario is focused on the analysis of impact of near faults to the assessed point in HV network. Fault location point SC3 (Fig.1) is near to the transformer 110kV/22kV which supplies the MV network (22kV). In the following figures are shown simulation results of phase voltage sags in LV network for cases: near line-to-line short-circuit and line-to-line short-circuit with earth connection in HV network (110kV).

Results of present simulation scenarios for case line-to-line short-circuit and line-to-line short-circuit with earth connection in the near 110 kV substation confirmed an occurrence of phase voltage sags in LV network. In case of the line-to-line short-circuit, the voltage sag was lower, equal to value 0.86 (p.u). The line-to-line short-circuit with earth connection caused the voltage sag in LV network, equal to value 0.63 (p.u).



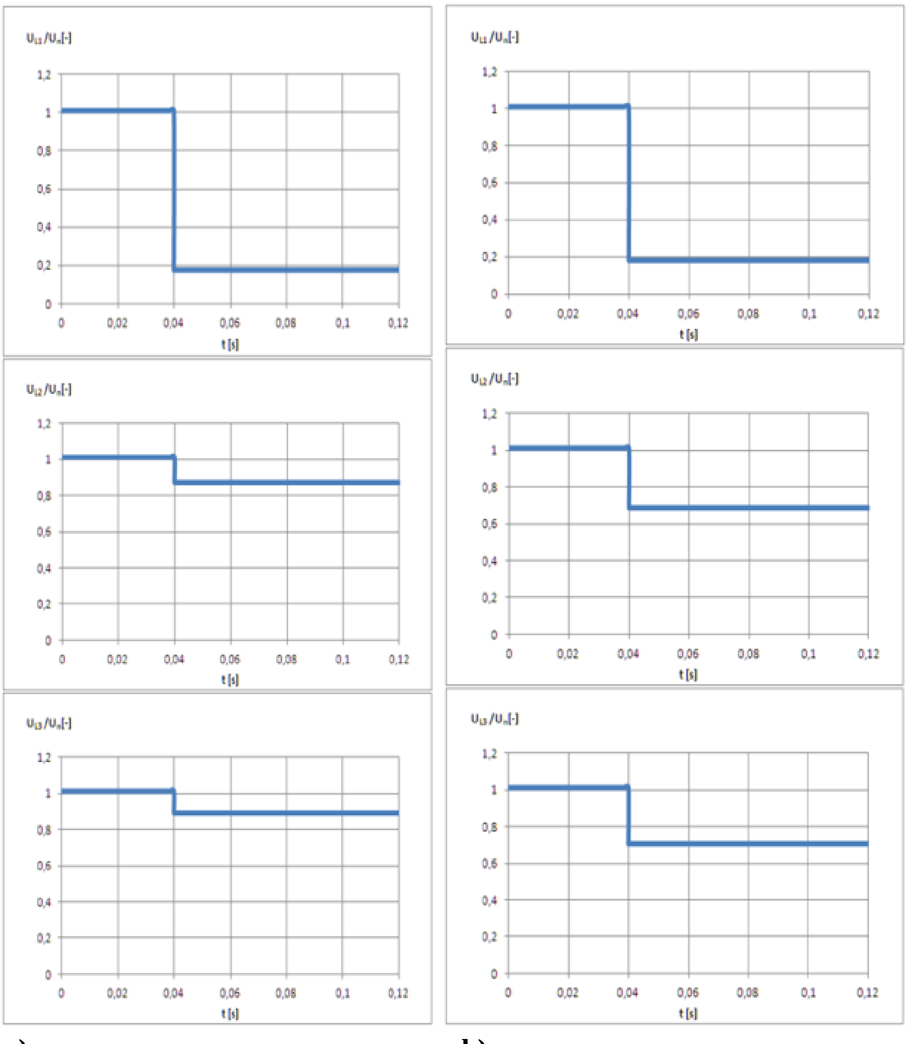
a) b)

Fig. 4 a) Phase voltage (p.u.) in LV network for case: near line-to-line short-circuit in 110kV network, b) Phase voltage (p.u.) in LV network for case: near line-to-line short-circuit with earth connection in 110kV network

4.3 Electrically Far Line-to-line Short-circuit and Line-to-line Short-circuit with Earth Connection in 110kV Network

In this case, considered fault was simulated in HV network (110kV) in electrically far point SC2 (Fig.1) from the transformer T1.1 supplying MV network (22kV). The aim of this simulation calculation is to analyze an impact of far fault in the HV network on voltage sags in LV network. In the following figures are shown simulation results of phase voltage sags in LV network for cases: electrically far line-to-line short-circuit, and line-to-line short-circuit with earth connection in HV network (110kV).

From the voltage waveforms, it results that electrically far faults cause almost the same magnitude of voltage sags in LV network as the near faults.



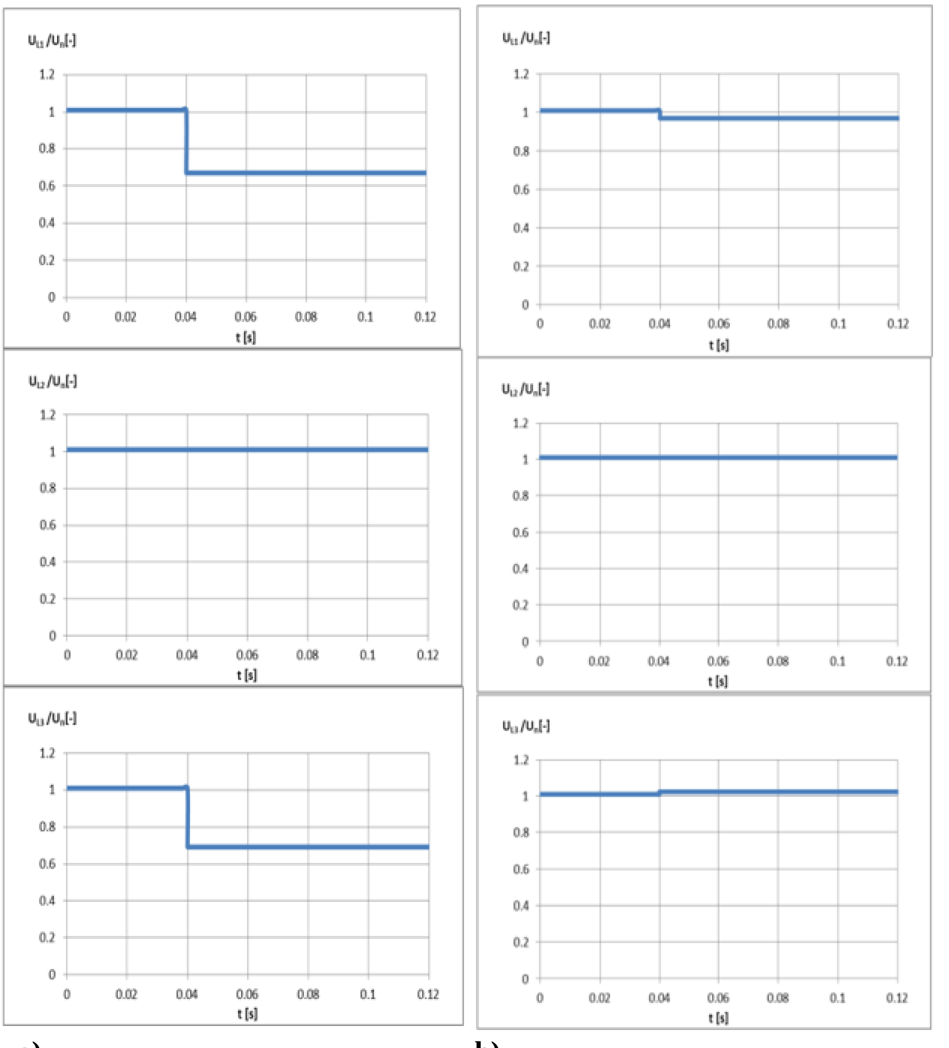
a) b)

Fig. 5 a) Phase voltage (p.u.) in LV network for case: far line-to-line short-circuit in 110kV network, b) Phase voltage (p.u.) in LV network for case: far line-to-line short-circuit with earth connection in 110kV network

4.4 Electrically Far Line-to-earth Short-circuit in 110kV Network with and without considering Fault Resistance

This simulation calculation is focused on the analysis of impact of fault resistance on voltage sags. In the following figures are shown simulation results of phase voltage sags in LV network for cases: line-to-earth short-circuit without a fault resistance and with a fault resistance 100Ω in SC2 (Fig.1).

From the comparison of simulation results, it clearly results the fault resistance significantly affects the impact of fault considering a fault resistance in HV network on the voltage sags in LV network.



a) **b)**

Fig. 6 a) Phase voltage (p.u.) in LV network for case: near line-to-earth short-circuit in 110kV network without fault resistance, b) Phase voltage (p.u.) in LV network for case: near line-to-earth short-circuit in 110kV network with fault resistance 100Ω

4.5 1st and the 2nd Earth Fault in Main Substation 110kV/22kV and near to Transformer 22kV/0.4kV T2 and T3

In MV network (22kV) were simulated different scenarios of earth faults. From given a large number of simulated scenarios of earth faults, this article shows results only of selected scenarios.

The first scenario represents the 1st earth fault in phase L1 in time 0.04s and the 2nd earth fault in time 0.08s in phase L2. The earth faults were simulated in the substation 110kV/22kV supplying a part of MV network (behind the transformer T1.1 on the 22kV busbar EF1 in Fig.2).

The second scenario represents the same type of fault in point EF3 near to assessed LV network. In the following figures are shown simulation results of phase voltage change for cases: earth fault in points EF1 and EF3 (Fig.2).

From the simulations results the 1st earth fault (in phase L1) in main 22kV substation does not affect voltage conditions in LV network. The 2nd earth fault (in phase L2) represents a line-to-line short-circuit with earth connection with a significant voltage sag in phase L1 in LV network.

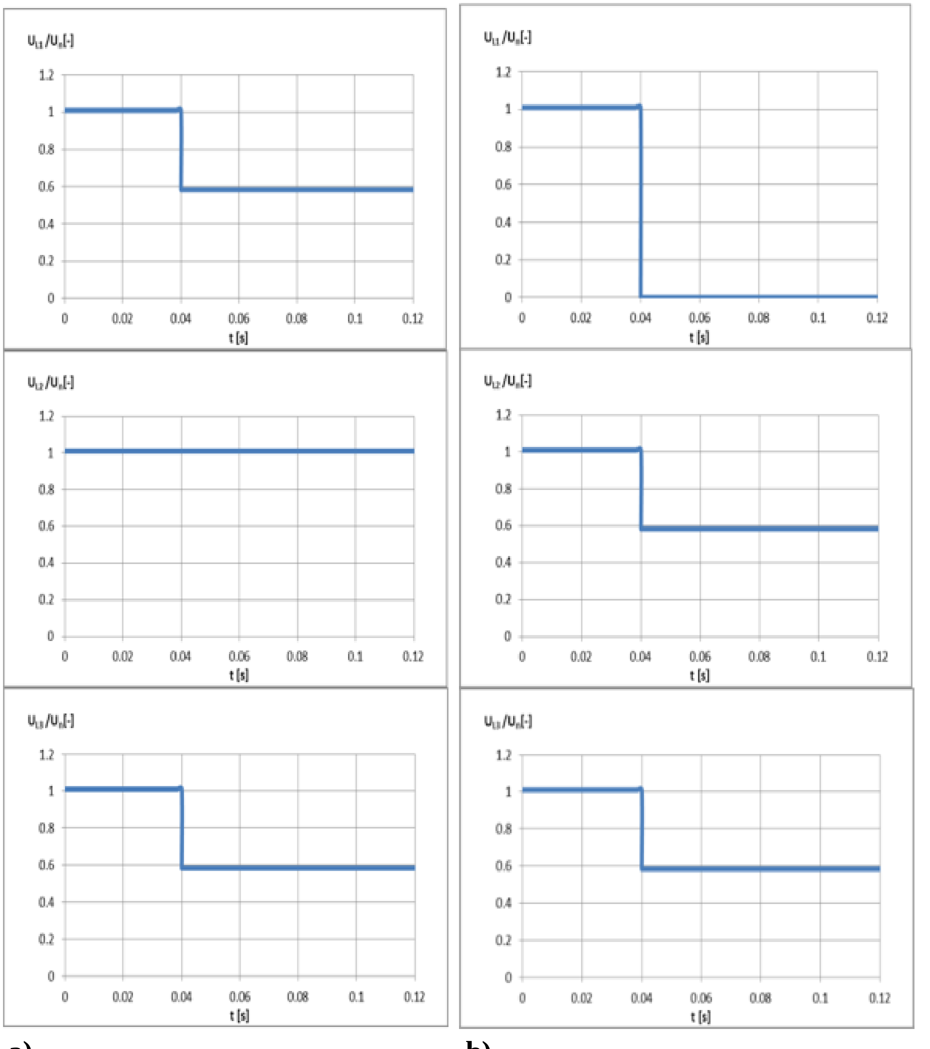


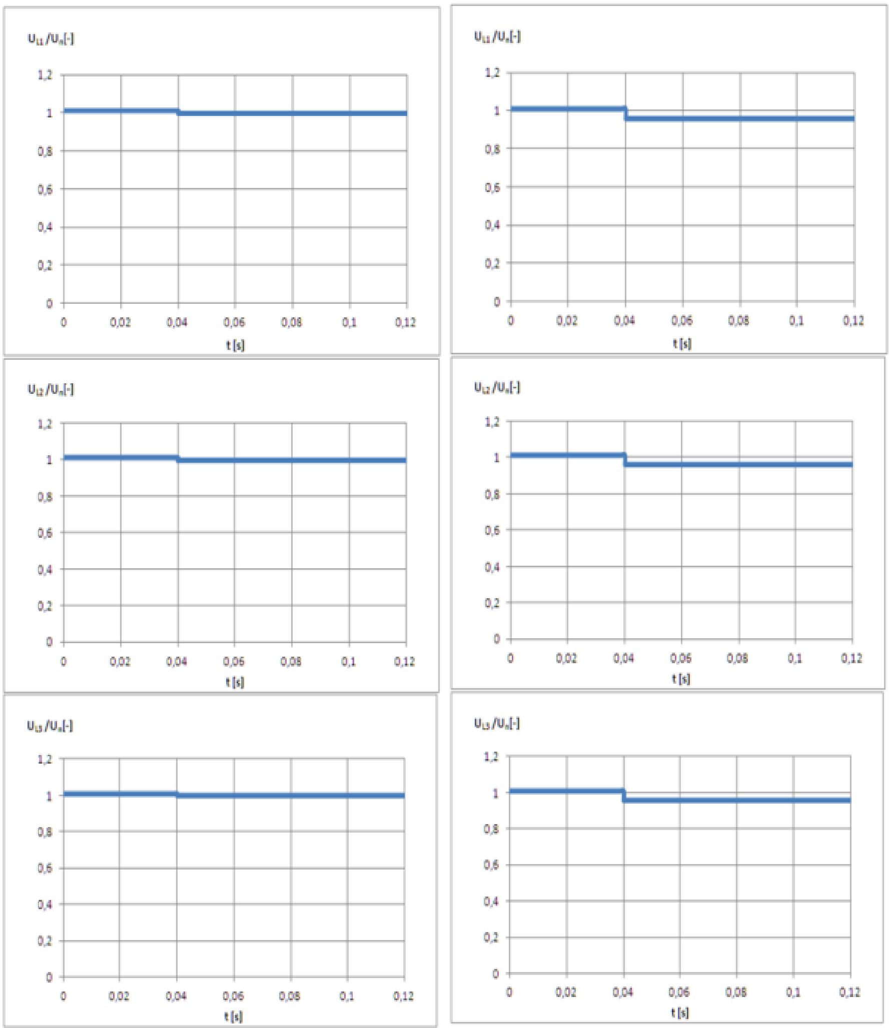
Fig. 7 a) Phase voltage (p.u.) in LV network for case: near earth fault in 22kV network (EF1), b) Phase voltage (p.u.) in LV network for case: near earth fault in 22kV network (EF3)

4.6 Three-phase Short-circuit in 0.4kV Network

Present calculation is focused on the evaluation of impact of three-phase short-circuits located in LV network supplied from the same 22kV network as the assessed low voltage network.

In the first case, three-phase fault was simulated on LV side of transformer 100kVA (see SC6 in Fig.2) and the second case on LV side of transformer 1250kVA (see SC7 in Fig.2). These calculations were selected in order to analyze fault impacts in different LV network supplied from transformer with high impedance (100kVA) and low impedance (1250kVA) on voltage sags, concretely on the transmission of failure into the assessed LV network.

From the voltage waveforms, it results the fault in LV network supplied from the same MV network does not have a significant impact on the voltage sags in the assessed LV network. On the other side, simulations confirmed an impact of different value of nominal power of transformer on the transmission of failure into the assessed LV network. Transformer with nominal power 1250kVA (with lower impedance) has more significant impact on the voltage conditions than transformer with nominal power 100kVA (with higher impedance).



a) **b)**

Fig. 8 a) Phase voltage (p.u.) in LV network for case: three-phase short-circuit in LV network supplied from transformer 100kVA (SC6), b) Phase voltage (p.u.) in LV network for case: three-phase short-circuit in LV network supplied from transformer 1250kVA (SC7)

5 Conclusion

The submitted paper deals with issue of analysis of impact of selected fault types located at different points in power system on voltage sags in the industry. Increase of automation in industrial sector brought problems related to voltage sags associated with wide using of electronic control circuits, i.e. technology sensitive to voltage sags. Failures of this equipment can lead in negative case to production restriction and cause significant technological and financial losses for consumer.

A suitable tool to avoid voltage sags is an assessment of voltage conditions using simulation analysis of selected various faults potentially most contributing to occurrence of voltage sags in the industrial distribution.

Assessment of voltage sags in industrial network is based on the simulation calculations for different types of faults (short circuits and earth faults) in the power system at different voltage levels.

The aim of simulation scenarios was to point out voltage response in industrial LV network considering different types of faults in selected locations in power system. From the simulations result the voltage response significantly depends on the type and impedance of fault.

In general, manners of elimination of voltage sags have to be implemented on the side of consumer as well as the system operator. The elimination of cautions of voltage sags from the distribution or transmission system is not completely possible due to an impact of variable unpredictable factors, such as meteorological factors (lightning, strong wind, frost, increased humidity), equipment age, fauna influence, the impact of operational factors such as overvoltage and so on. These phenomena are therefore necessary to minimize at the possible lowest level. In order to avoid the production restriction in the industry area, it is necessary to do more steps on both sides. The transmission and distribution system operators should perform proper and regular maintenance service in their networks. On the other side, industrial customers should perform the measurements in order to select the most sensitive equipment and increase their ability to withstand any potential voltage sags.

And therefore, it is possible to use one application of the following methods:

- Immunity increase of the sensitive equipment or process (technology),
- Installation of special devices between the sensitive equipment (technology) and power supply network,
- Elimination methods at the distribution or transmission grid.

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