# Development of an Algorithm and Software "MVES-TV 2012" for Touch Voltage Evaluation in MV Networks

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***Abstract*. The paper presents an algorithm for evaluation of touch voltage in medium voltage networks with different types of neutral earthing. The proposed algorithm takes into account power line type (overhead line, underground cable line), earth fault value, number of substations, etc.**

**Based on this algorithm, new software "MVES-TV 2012" (Medium Voltage Electrical System Touch Voltage) is developed by the authors of this paper. Evaluation with this software ensures the safety of human life in any switchgear place to which persons have legitimate accesses.**

**This software can be useful for distribution network project and exploiting engineers when trying to evaluate touch voltage in medium voltage networks.**

***Keywords*: Distribution of electrical energy, safety, software.**

## I. INTRODUCTION

The major consideration why substation is so well-grounded is personnel protection. Equipment protection is just one of the other reasons.

A continuous current of 0.15 A flowing through the trunk part of the body is almost always fatal. In assessment of touch voltage in case of one phase earth fault for the medium voltage networks, it is important to understand the electrical characteristics of the most important part of the circuit, the human body. [1]

The earth potential rise of an earthing system may be calculated from available data (impedance to earth of existing earthing systems, switchgear and network schemes etc.). For the calculation all earth electrodes and other earthing systems, which are reliably connected to the relevant earthing system with sufficient current carrying capacity, may be considered.

## II. EFFECTS OF CURRENT ON HUMAN BODY

In general, shock currents are classified based on the degree of severity of the shock they cause. For example, currents that produce direct physiological harm are called primary shock currents. However, currents that cannot produce direct physiological harm, but may cause involuntary muscular reactions are called secondary shock currents. These shock currents can be either steady-state or transient in physiological harm, but may cause involuntary muscular reactions are called secondary shock currents. These shock currents can be either steady-state or transient in nature. In AC power systems steady-state currents are sustained currents of 50Hz or its harmonics nature. In AC power systems steady-state currents are sustained currents of 50Hz or its harmonics. The transient currents, on the other hands, are capacitive currents whose magnitudes diminish rapidly with time.

The threshold value for a normally healthy person to be able to feel a current is about 1mA. This is the value of a current at which a person is just able to detect a slight tingling sensation on the hands or fingers due to current flow.

Currents of 1mA or more but less than 6mA are often defined as the secondary shock currents. The shock current is the maximum current level at which a human holding an energized conductor can control his or her muscles enough to release it. Currents of approximately 10-30mA can cause lack of muscular control. In most humans, a current of 100mA will cause ventricular fibrillation. Currents of higher magnitudes can stop the heart completely or cause severe electrical burns. [1]

There are four main effects in case of current flow through the human body: tetanization, breathing arrest, ventricular fibrillation and burns. All of these effects in certain circumstances may lead to the death.

The most dangerous is ventricular fibrillation because external currents induce alterations of the cardiac cycle by generating uncontrolled contractions. This anomaly may become an irreversible phenomenon since it persists even when the stimulus has ceased.

Just as dangerous is breathing arrest because if the current flows through the muscles controlling the respiratory system, the involuntary contraction of the muscles alters the normal respiratory process and the subject may die.

Tetanization itself are rarely fatal, but it prolongs the contact with the conductive parts which gripped is difficult if current is not very high. In the case of very high currents a person sustains mechanical traumas because the muscular contraction is so sustained that the involuntary muscle movements generally throw the subject away from the conductive part.

The less dangerous are burns because they can become dangerous if the burn is larger than the victim's palm or have occurred internal burns. [2], [3]

All of these effects in certain circumstances may lead to the death. Therefore, its threshold is the main concern in earthing design. For 99.5% of population, the-50Hz mini mum required body current, $I_B$, leading to possible fatality through ventricular fibrillation can be expressed as:

$$I_B = \frac{C_{BW}}{\sqrt{t_S}},\text{(A)} \qquad (1)$$

where $t$ is in seconds in the range from approximately 8.3 ms to 5 s, $C_{BW}$ is coefficient dependent on the body weight (0.116 for 50kg body weight and 0.157 for 70kg body weight).

Taking into account total human body impedance and a hand to feet current path a correction factor of 0.75 for the body impedance is calculated permissible touch voltage (the part of the earth potential rise due to an earth fault which can be picked up by a person, assuming that the current is flowing via the human body from hand to feet) and shown in Fig.1. [3], [5]:

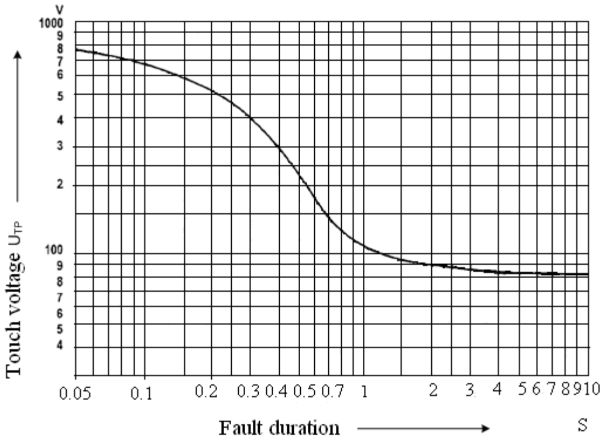


Fig.1 Calculated values of the permissible touch voltage $U_{TP}$ as a function of the fault duration $t_F$.

As can be seen in Fig. 1 there is significant difference in 0.04 seconds permissible touch voltage (800V) and 5 seconds permissible touch voltage (85V).

Fig. 2 shows the comparison of earth surface potential distribution (SDP) during the current flow in the earthing system, for two earth electrode constructions.

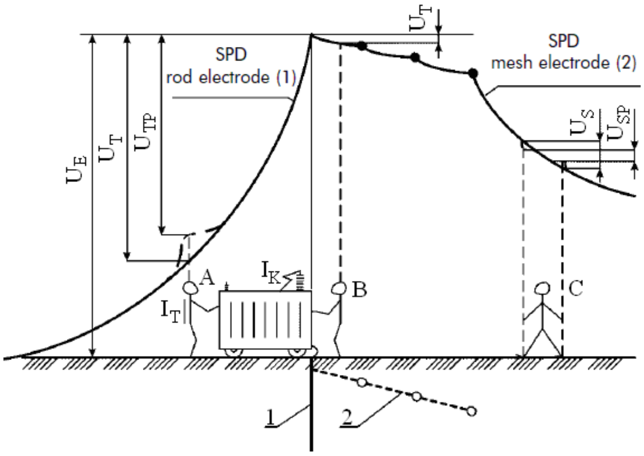


Fig.2 Comparison of earth surface potential distribution (SDP) during the current flow in the earthing system, for two earth electrode constructions.

Persons A and B are subject to the touch potential while person C is subject to the step potential. The touch voltage $U_T$ is sometimes differentiated from the permissible touch voltage $U_{TP}$, (and step voltage $U_S$ from the shocking step voltage $U_{SP}$) Voltages $U_T$ and $U_S$ are the pure values resulting from the potential distribution, whereas $U_{TP}$ and $U_{SP}$ consider the small changes in potential distribution caused by flowing of shocking current – i.e. including the distorting effect of the current flow through the person. In practice the difference between $U_S$ and $U_{SP}$ or $U_T$ and $U_{TP}$ is usually small, so that the same values for the respective potentials are assumed: $U_S \approx U_{SP}$ and $U_T \approx U_{TP}$.

The rod electrode (1) has a low resistance but most unfavorable potential distribution while the meshed electrode (2) has a much flatter earth potential profile. The touch potential (person A) is considerably larger for the rod electrode (1) than for the meshed one (2), (person B). Step potentials (person C) are also less dangerous in the case of the meshed electrode. [10], [7]

## III. NEUTRAL EARTHING

In touch voltage calculation should be taken into account type of neutral earthing. Paper presents two of neutral earthing types- low resistance and compensated neutral earthing.

### A. *System with low resistance neutral earthing*

System with low resistance neutral grounding is a system where at least one of the neutral points is connected to earth via a low resistance resistor. System with low resistance neutral grounding is shown in Fig.3. [5], [8]

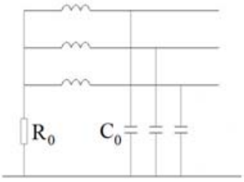


Fig.3. System with low resistance neutral grounding.

The purpose of the neutral point resistor is to increase the resistive part of the earth fault current and hence improve the earth fault detection.

System with low resistance neutral grounding immediately disposes of two defects of the isolated system: it permits ready relaying of ground faults and it minimizes the hazard of arcing grounds. In general the grounding resistances used to have limited the ground-fault current to a magnitude much less than the three-phase short-circuit current. [5], [8]

Low resistance earthing of the neutral limits the earth fault current to a high level (typically 50A or more) in order to operate protective fault clearing relays and current transformers. These devices are then able to quickly clear the fault, usually within a few seconds (less than 5 seconds). The importance of this fast response time is that it:

- limits damage to equipment;
- prevents additional faults from occurring;
- provides safety for personnel;
- localizes the fault.

The limited fault current and fast response time also prevent over-heating and mechanical stress on conductors. Low resistance earthing resistors are typically rated 400A for 10 seconds, and are commonly found on medium and high voltage systems. [6]

### B. *System with compensated neutral earthing*

Compensated neutral system is a system in which at least one of the neutrals is connected to earth via an inductive reactance, a Petersen coil, and the current generated by the reactance during an earth fault approximately compensates the capacitive component of the single phase earth fault current. Compensated neutral system is shown in Fig.4. [5],[8]

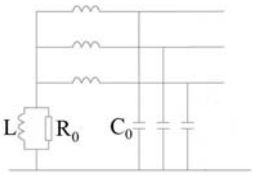


Fig.4. Compensated neutral system [5],[8].

The system is hardly ever exactly tuned, i.e. the reactive current does not exactly equal the capacitive earth fault current of the system. A system in which the inductive current is slightly larger than the capacitive earth fault current is over compensated. A system in which the induced earth fault current is slightly smaller than the capacitive earth fault current is under compensated.

The neutral point reactor is often combined with a neutral point resistor. In a compensated grounded system the resulting reactive part of the earth fault current is too small for the relay protection to measure. In addition to this, there will always be active losses in the neutral point generator, which contributes to the active part of the earth fault current. Typical examples of power systems with strong capacitive connection to earth, suitable for resonant grounding, are the systems consisting of an extensive amount of cables. If the high capacitive earth fault current of such systems is not compensated, the risk of dangerously high potential rise of exposed parts of the power system is evident. [5], [8]

### *C. System with isolated neutral earthing*

Isolated neutral system is the system where all transformer neutrals are ungrounded. The only intentional connection between an ungrounded neutral and earth is via high impedance equipment for protection or measurement purposes such as surge arresters or voltage transformers. In a power system there are however always capacitive connections between the phases and earth. The strength of the capacitive connection depends on type and length of the power system circuit. When an earth fault occurs in the system, the capacitance to earth of the faulty phase is bypassed. Isolated neutral system is shown in Fig. 5. [5], [8]

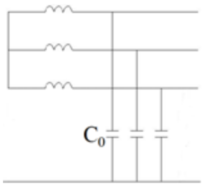


Fig.5. Isolated neutral system [5], [8]

## IV. Earth Fault

Fig. 6 represents the current, voltage and resistance in case of earth fault in zone of distribution transformer, where: *r*-reduction factor of metal shell; $3\underline{I}_0$-three times zero sequence current of the line; $\underline{I}_F$ -earth fault current; $\underline{I}_E$ - current to earth; $\underline{I}_{RS}$-current via the resistance to earth of the mesh earth electrode; $\underline{R}_{ES}$- resistance to earth of the mesh earth electrode; $\underline{Z}_\infty$- chain impedance of the overhead line assumed to be infinite.

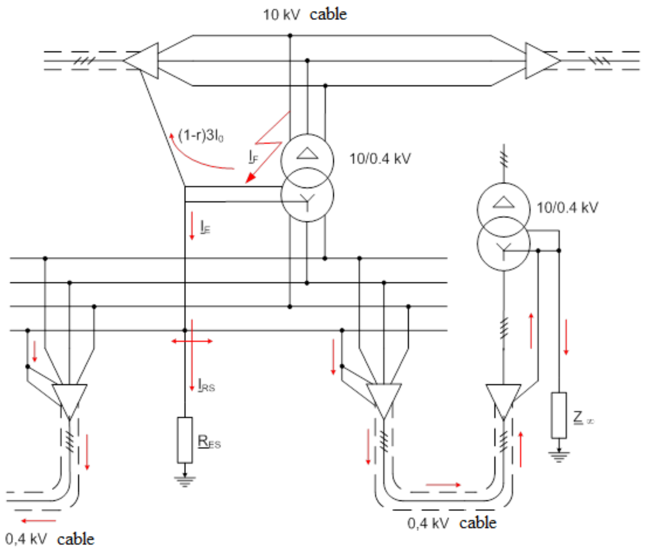


Fig.6. Current, voltage and resistance in case of earth fault in zone of distribution transformer.

Fig. 6 and Fig. 7 show the substitution scheme of earth fault in zone of distribution transformer, where $\underline{U}_E$ is earth potential rise.

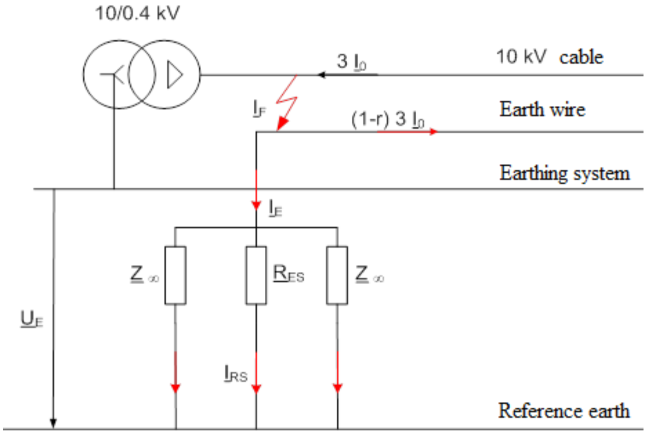


Fig.7. Substitution scheme of earth fault in zone of distribution transformer.

## V. Algorithm for Evaluation of Touch Voltage in MV Networks with Compensated Neutral Earthing

In evaluation of touch voltage it should be taken into account earth fault current value at substation, resistance to earth at substation, earth electrode impedance at substation, number of substations and type of cable. Fig.8 represents the algorithm for evaluation of touch voltage in MV networks with compensated neutral earthing. [7], [8]

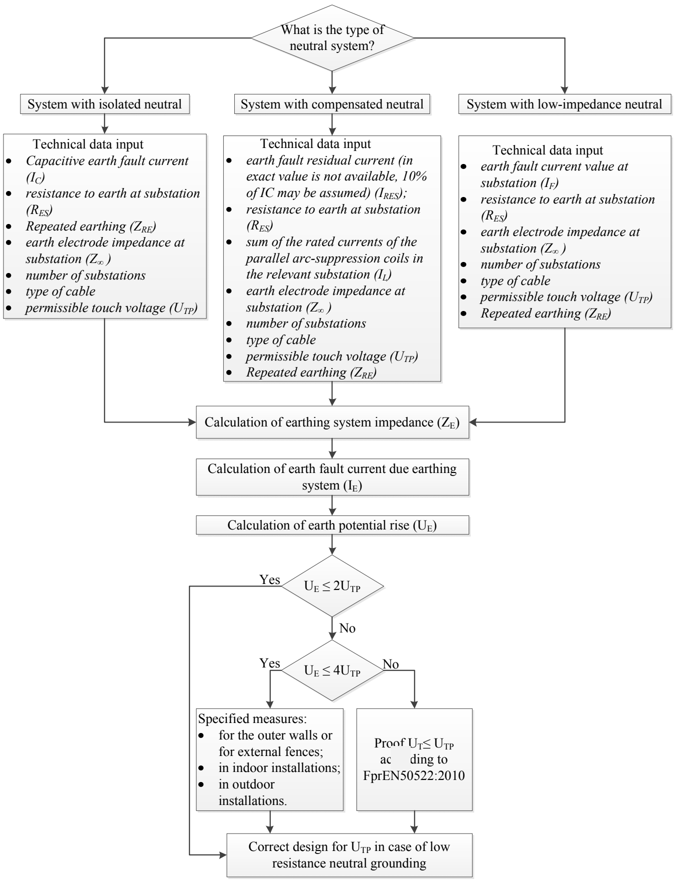


Fig.8. Algorithm for evaluation of impedance to earth at substation in MV networks with low resistance and compensated neutral earthing.

At the first step it is necessary to calculate earthing system impedance $Z_E$:

$$Z_E = \frac{1}{\frac{1}{R_{ES}} + n \cdot \frac{1}{Z_\infty} + \frac{1}{Z_{RE}}} \ (\Omega) \qquad (2)$$

where $R_{ES}$- resistance to earth at substation (Ω), $n$- number of substation, $Z_\infty$- earthing electrode impedance at substation (Ω), $Z_{RE}$- repeated earthing (Ω).

At the second step earth fault current according to the earthing system $I_E$ should be calculated for each neutral earthing type separately:

- for compensated neutral system:

$$I_E = r \cdot \sqrt{I_L^2 + I_{RES}^2} \ \text{(A)} \qquad (3)$$

where r- reduction factor (factor r of a three phase line is ratio of the current to earth over the sum of the zero sequence currents in the phase conductors of the main circuit at a point remote from the short-circuit location and the earthing system of an installation, $I_L$-sum of the rated currents of the parallel arc-suppression coils in the relevant substation (A), $I_{RES}$-earth fault residual current (in exact value is not available, 10% of $I_C$ may be assumed) (A);

- for low impedance neutral system:

$$I_E = r \cdot I_F \ \text{(A)} \qquad (4)$$

where $r$- resistance to earth at substation, $I_F$-earth fault current value at substation (A);

- for isolated neutral system:

$$I_E = r \cdot I_C \ \text{(A)} \qquad (5)$$

where $r$- resistance to earth at substation, $I_C$-capacitive earth fault current (A).

At the third step it is necessary to calculate earth potential rise $U_E$:

$$U_E = I_E \cdot Z_E \ \text{(V)} \qquad (6)$$

where $I_E$- earth fault current due earthing system (A), $Z_E$- earthing system impedance (Ω);

At the fourth step the earth potential rise should be assessed, i.e., if touch voltage does not exceed permissible touch voltage $U_{TP}$ two times:

$$U_E \leq 2U_{TP} \qquad (7)$$

If $U_E > 2U_{TP}$ , then the earth potential rise is assessed, i.e., if touch voltage does not exceed permissible touch voltage $U_{TP}$ four times:

$$U_E \leq 4U_{TP} \qquad (8)$$

If $U_E > 4U_{TP}$, then $U_T \leq U_{TP}$ is proved according to EN 50522:2010. [7], [8]

If $U_E > 4U_{TP}$, then specified measures should be applied:

1. for the outer walls or external fences:

- use of fences of non-conductive material or of a plastic-covered wire mesh;
- when using fences of conductive material, potential grading by a horizontal earth electrode, which is connected to the fence, at a distance of approximately 1 m outside the fence and at a maximum depth of 0.5 m. The connection of the fence to the earthing system is optional;
- insulation of the operating location in accordance with recognized specified measure and earthing of the fence either or by connection with the earthing system;
- if gates in external fences are connected directly to the earthing system or via protective conductors or metal sheaths of cables for staff locator systems etc., then at the opening area of the gates a potential grading or insulation of the operating location in accordance with recognized specified measure has to be applied;
- use of non-conductive material for the outer walls and avoidance of earthed metal parts which can be touched from outside;
- potential grading by a horizontal earth electrode which is connected to the earthing system, at a distance of

- approximately 1 m outside the outer wall and at a maximum depth of 0.5m;
- insulation of the operating location: the layers of insulating material shall be of sufficient size, so that it is impossible to touch the earthed conductive parts with the hand from a location outside the insulating layer.

2. in indoor installations one of these:

- equipotential grading by embedding grid-type electrodes in the building foundations and connection to the earthing system at a minimum of two separate locations;
- construction of the operating locations from metal and connection to any metal parts which have to be earthed and which can be touched from the operating location;
- insulation of the operating locations for the earth potential rise in accordance with recognized specified measure. For equipotential bonding the metal parts which have to be earthed and which can be simultaneously touched from the operating location, have to be interconnected.

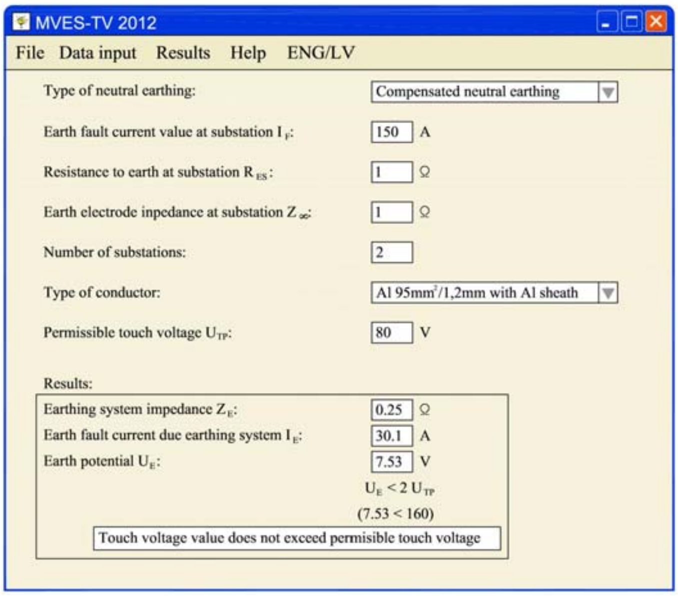
3. in outdoor installations:

- At operating locations should be made one of these measures:
  - ✓ potential grading by a horizontal earth electrode at a depth of approximately 0.2m and a distance of approximately 1m from the equipment to be operated. This horizontal earth electrode has to be connected to all metal parts which have to be earthed and which can be touched from the operating location;
  - ✓ construction of the operating locations from metal (for example metal grid or metal plate) and connection to the metal parts which have to be earthed and which can be touched from the operating location;
  - ✓ For equipotential bonding the metal parts which have to be earthed and which can be simultaneously touched from the operating location, have to be interconnected.
- burying a horizontal earth electrode surrounding the earthing system in the form of a closed ring. Inside this ring, a meshed earth grid has to be buried, whose individual meshes have a maximum size of 10x50m. At individual parts of the installation, which are situated outside of the ring and which are connected to the earthing system, a grading earth electrode at a distance of approximately 1 m and depth of approximately 0.2 m has to be provided. [3], [9]

## VI. SOFTWARE “MVES-TV 2012” TEST

Software “MVES-TV 2012” developed by the authors was tested. The results are shown in Fig.9 and Fig.10. It is easy verify results, if use equations (2), (3), (4) and (5).

Fig. 9 shows the example of evaluation in case of cable lines. In this case touch voltage value does not exceed permissible touch voltage.



Type of neutral earthing: Compensated neutral earthing

Earth fault current value at substation $I_F$: 150 A

Resistance to earth at substation $R_{ES}$: 1 Ω

Earth electrode inpedance at substation $Z_\infty$: 1 Ω

Number of substations: 2

Type of conductor: Al 95mm$^2$/1,2mm with Al sheath

Permissible touch voltage $U_{TP}$: 80 V

Results:

Earthing system impedance $Z_E$: 0.25 Ω

Earth fault current due earthing system $I_E$: 30.1 A

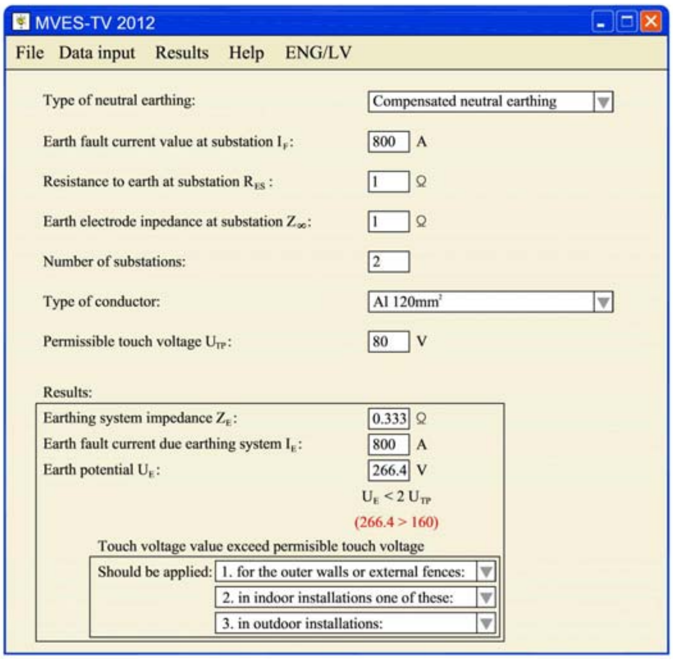
Earth potential $U_E$: 7.53 V

$U_E < 2\,U_{TP}$

(7.53 < 160)

Touch voltage value does not exceed permisible touch voltage

Fig.9. MVES-TV 2012 evaluation in case of cable lines.



Type of neutral earthing: Compensated neutral earthing

Earth fault current value at substation $I_F$: 800 A

Resistance to earth at substation $R_{ES}$: 1 Ω

Earth electrode inpedance at substation $Z_\infty$: 1 Ω

Number of substations: 2

Type of conductor: Al 120mm$^2$

Permissible touch voltage $U_{TP}$: 80 V

Results:

Earthing system impedance $Z_E$: 0.333 Ω

Earth fault current due earthing system $I_E$: 800 A

Earth potential $U_E$: 266.4 V

$U_E < 2\,U_{TP}$

(266.4 > 160)

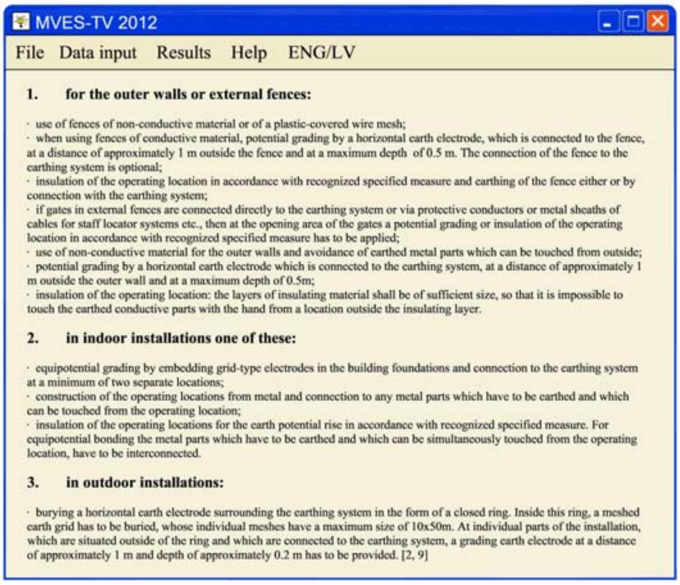
Touch voltage value exceed permisible touch voltage

Should be applied: 1. for the outer walls or external fences:

2. in indoor installations one of these:

3. in outdoor installations:

Fig. 10. MVES-TV 2012 evaluation in case of overhead lines.



**1. for the outer walls or external fences:**

- use of fences of non-conductive material or of a plastic-covered wire mesh;
- when using fences of conductive material, potential grading by a horizontal earth electrode, which is connected to the fence, at a distance of approximately 1 m outside the fence and at a maximum depth of 0.5 m. The connection of the fence to the earthing system is optional;
- insulation of the operating location in accordance with recognized specified measure and earthing of the fence either or by connection with the earthing system;
- if gates in external fences are connected directly to the earthing system or via protective conductors or metal sheaths of cables for staff locator systems etc., then at the opening area of the gates a potential grading or insulation of the operating location in accordance with recognized specified measure has to be applied;
- use of non-conductive material for the outer walls and avoidance of earthed metal parts which can be touched from outside;
- potential grading by a horizontal earth electrode which is connected to the earthing system, at a distance of approximately 1 m outside the outer wall and at a maximum depth of 0.5m;
- insulation of the operating location: the layers of insulating material shall be of sufficient size, so that it is impossible to touch the earthed conductive parts with the hand from a location outside the insulating layer.

**2. in indoor installations one of these:**

- equipotential grading by embedding grid-type electrodes in the building foundations and connection to the earthing system at a minimum of two separate locations;
- construction of the operating locations from metal and connection to any metal parts which have to be earthed and which can be touched from the operating location;
- insulation of the operating locations for the earth potential rise in accordance with recognized specified measure. For equipotential bonding the metal parts which have to be earthed and which can be simultaneously touched from the operating location, have to be interconnected.

**3. in outdoor installations:**

- burying a horizontal earth electrode surrounding the earthing system in the form of a closed ring. Inside this ring, a meshed earth grid has to be buried, whose individual meshes have a maximum size of 10x50m. At individual parts of the installation, which are situated outside of the ring and which are connected to the earthing system, a grading earth electrode at a distance of approximately 1 m and depth of approximately 0.2 m has to be provided. [2, 9]

Fig.11. MVES-TV 2012 proposed recommendations.

Fig. 10 shows the example of evaluation in case of overhead lines. In this case touch voltage value exceed permissible touch voltage therefore is given recommendations for reducing touch voltage. From each group of proposed recommendations must be selected one single measure (see. Fig. 11)

## VII. CONCLUSION

An algorithm for evaluation of touch voltage in medium voltage networks with different type of neutral earthing in paper was made. Proposed algorithm takes into account power line type (overhead line, underground cable line), earth fault value, number of substations, etc.

Based on this algorithm new software "MVES-TV 2012" (Medium Voltage Electrical System Touch Voltage) is developed by the authors of this paper. Evaluation with this software ensures the safety of human life in any switchgear place to which persons have legitimate accesses.

This software can be useful for distribution network exploiting engineers when trying to evaluate of permissible touch voltage in medium voltage networks with different type of neutral earthing.

With this software it will be easily and quickly to evaluate of permissible touch voltage in medium voltage networks with different type neutral earthing.

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Her employment experience includes Institute of Physical Energetics- Laboratory of Electric Power System Simulation. Her special field of interests includes methods for touch voltage calculation, methods for selection of neutral grounding mood, methods for reliability evaluation of medium voltage electrical networks and systems and methods for development of medium voltage power systems planning.

She is author of more than 10 papers.

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Principal investigator of the Latvian Scientific Council grant 05.1683. He was project manager of the European Commision project "Eurowin" from Latvian part (1994-1996) and more than 20 contracts with Latvenergo regarding medium voltage network neutral earthing. He was awarded with Year price of Latvian Academy of Science and Latvenergo in power engineering (2004).

**Ilze Priedite-Razgale, Janis Rozenkrons. Attīstības algoritmu un "MVES-TV 2012" programmatūras skārienjūtīga sprieguma novērtēšana vidējā sprieguma tīklā**

Būtiskākai apakšstacijās ir personāla drošība, tādēļ tās ir labi zemētas. Otrs iemesls ir iekārtas aizsardzības iemesliem. Nepārtraukta strāva 0,15 A plūstot caur daļu no ķermeņa, gandrīz vienmēr ir letāla. Izvērtēšana skārienjutīgā sprieguma gadījumā vienas fāzes īsslēguma vidēja sprieguma tīklos, ir svarīgi saprast elektriskās īpašības svarīgākajām kontūra daļām, kur iesaistīts cilvēka ķermenis. Zemes potenciāla pieaugumu no zemējuma sistēmas var aprēķināt no pieejamiem datiem (pilnā pretestība uz zemi eksistē zemēšanas sistēmas, komutācijas aparāti un tīkla shēmas u.c.). Var apskatīt gadījumu, lai aprēķinātu zemējumu elektrodus un citas zemēšanas sistēmas, kuras ir droši piemērotas attiecīgai zemēšanas sistēmai un ar pastāvošo strāvas lielumu. Publikācijā tika piedāvāts novērtēt skārienjutīgā spriegumu algoritmu vidsprieguma tīklos ar dažādiem neitrāles zemējumu veidiem. Piedāvātais algoritms ņem vērā elektropārvades līnijas tipus (gaisvadu līnijas, kabeļu līnijas), zemesslēgumu bojājumus, apakšstaciju skaits u.c. Pamatojoties uz šo algoritmu, ir izstrādāta jauna programmatūra "MVES-TV 2012" (Vidēja Sprieguma Elektriskās Sistēmas Skārienjūtīgs Spriegums), kuru izstrādāja šī raksta autori. Šīs programmatūras aprēķins nodrošina aizsardzību cilvēku dzīvībām, jebkurā komutācijasaparāta vietā, kur apkalpojošam personālam ir piekļuve. Šī programmatūra var būt noderīga, sadales tīklu inženieru praktiskā darbā, novērtējot pieļaujamo skārienjutīgo spriegumu vidsprieguma tīklos ar dažādu veidu neitrāļu zemējumiem. Izmantojot šo programmatūru tas būs viegli un ātri izvērtējot pieļaujamo skārienjutīgo spriegumu vidsprieguma tīklos ar dažāda tipa neitrāļu zemējumu.

**Илзе Приедите-Разгале, Янис Розенкронс. Разработка алгоритма и программного обеспечения "MVES-TV 2012" с сенсорной оценкой напряжения в сети среднего напряжение.**

Электробезопасность обслуживающего персонала является основной причиной заземлений распределительных устройств. Если через тело протекает переменный ток 0,15A, то последствия, как правило, летальные. Для оценки напряжения в сети среднего напряжения важно представить электрические свойства тела человека в электрической цепи. Напряжение на заземлитель определяется по сопротивлению растекания заземлителя и тока замыкания на землю.

В публикации представлен алгоритм расчета этого напряжения для разных режимов нейтрали сети среднего напряжения с учетом вида линий (воздушные или кабельные), числа сетевых подстанций и т.д. На базе этого алгоритма авторы статьи разработали компьютерную программу MVES-TV 2012 (Medium Voltage Electrical System Touch Voltage). Программа предназначена для инженеров эксплуатации и проектирования распределительных сетей среднего напряжения.