Design thinking for innovation in 3D VR Over-Voltage Protection with Memristor

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***Abstract*— This paper shows an example of CogInfoCom as during analyses the operation of a memristor in a real 3D VR based teaching. This paper looks at the possibility of the application of a macroscopic memristor (MR), not yet available, combined with a spark gap for over-voltage protection purposes. During teaching the memristor as a disruptive technologies the lecturers and the students do a close cooperative work in the 3D VR space, using several mathematical softwares for analyzing of not yet avaliable memristor, so the humans and ICT are not separable on cognitive level. In this 3D VR education the cooperation of the intelligent systems with humans help to analyse, systemize the information and create new information.**

Memristors will possibly find applications in the field of electromagnetic compatibility, specifically in over-voltage protection, so it is timely to include it in the curriculum of electrical engineering education in BsC level. The examination of a physically non-existent memristor is made possible by 3D VR space and mathematical and infocommunication softwares.

So, presenting another cost-effective opportunity for the educational applicability of VR.

Keywords—Memristor; CogInfoCom; VR education; cognitive process

I. Introduction

Information plays a key role in 21st century education. Top Career Skills for a new generations are fast information search, selection of relevant information, efficient information processing, synthesis and utilization. Today is very important the creativity, problem-solving and innovative thinking. The Future Internet, the 5G network, the 3D VR, AR, and AI among the infocommunicational technologies as the key technologies of the 21st century has an effect on the information processing as well. Instead of previous analytical thinking with step-by-step information processing comprehensive spatial-visual processing is increasingly common [1]. The human brain is an experience-dependent system that responds to environmental influences. Gerontological studies show that people who spend a lot of time browsing on Internet are more active in the decision-making and problem-solving regions [2].

The new generations - CE generations [3] - students who are basically socialized in the cyber-life and in a cooperative ICT environment in a Human ICT combo way of life. The CogInfoCom [4,5] researches show that the cooperation of the intelligent systems in the virtual digital space efficiently help to find and process information with the help of reality extended with the learnning processes. The VR Learning Center research Lab at Széchenyi István University investigates the effects of 3D VR spaces on cognitive abilities, based on the Cognitive Infocommunication discipline. The VR Learning Center is responsible for disseminating research results. In collaboration with other universities, we are conducting extensive research on 3D VR education related topics.

This paper presents the results of research conducted in cooperation with the Faculty of Technology and Informatics of the University of Pécs. The paper analyses the possibility of the application of an MR combined with a spark gap for over-voltage protection purposes. Such macroscopic MRs are not yet available, however, their appearances can be expected in the near future. The education and the research was conducted among the students of PTE Faculty of Engineering and Information Technology. The survey was based on design thinking method for innovation and direct perception. The paper focuses on the presentation of technical solution.

The paper is structured as follows. In the first section, the previous VR research results and design thinking method that establishing the research will be briefly presented. Then the opportunity of application of memristor in the field of over-voltage, than the structure and operation, as a foundations of research will be presented.

In the next section the measure of dissipated surge energy and research results are summarized. Finally, in conclusion a dicussion is provided implemented so that the VR education will most effectively stimulate the effective learning in the field of innovative engineering education.

II. Background and applied 3D VR environment

Design thinking is an iterative approach to problem solving. Design thinking uses a process-based approach to solve problems and like any process, it involves a series of steps that are carried out in a particular order to achieve a goal. Design thinking focuses on uncovering human needs, ideas and doing [22]. It entails developing a point of view about what needs to address, generating quick solutions, prototyping. Design thinking is ideal for tackling complex problems such as engineering or designing a non-existent device like the current memristor. Primarily was used as an innovation strategy for designing objects and services for business. Has been increasingly applied to the creation of objects, delivery of services more recently. This project focuses on strives to make disruptive technologies and ideas tangible at an early stage. Based on an article on the experience of teaching disruptive technologies at an early stage [15], we designed VR education on this topic.

In this case, the goal is to identify a solution that is capable of succeeding at the possibility of the application of a macroscopic memristor (MR), not yet available, combined with a spark gap for over-voltage protection purposes. The objective of this analysis is to find the characteristics of the MR suitable for the above purpose, supported by an example according to the IEC 61000-4-5 [23] standard.

The VR Learning Lab at the Széchenyi István University has published several results in the past which focus on how digital information can be shared and understood faster and organized into more effective workflows. Several studies have been conducted on how VR in general and MaxWhere in particular can enhance the way students collaborate and learn. Studies have shown, among others, that [6-19] users are able to complete a set of digital workflows given to them at least 50% faster in 3D, when using the MaxWhere 3D environment as opposed to traditional educational platforms [6]. Further, both less user and less machine operations (by up to 30% and 80%, respectively) are required to complete the same workflow in 3D compared to using traditional 2D approaches [7]. The rate of memory recall was 50% higher if the visual information was inserted directly into the 3D environment that in it was indirectly inserted (embedded into an article) [8]. Virtual reality can be used to enhance student learning and engagement [20, 21].

In this project we regard VR first and foremost as a breakthrough platform for design thinking – as a new kind of cognitive infocommunication channel for using and interacting several mathemtical and design softwares. The chosen VR space helps the collaboration, but also provides an opportunity for individual analytical work (Fig. 1.).

Fig. 1. One unit of the proposed over-voltage protective device

III. Application of memristor in the field of over-voltage protection

Over-voltage protection is an important part of electromagnetic compatibility (EMC); protecting electric/electronic circuits against often irreversible damages. Spark gaps are useful and cheap means of over-voltage protection, allowing most possible low leakage current between the working conductor(s) (line and/or neutral conductor) and the protective earth (PE) conductor in their switched-off (idle) state. In their switched-on state, these devices have very low impedance; therefore not being able to dissipate a significant part of the energy of the surge that has been triggering their protective operation. Therefore spark gaps are often connected in series with varistors taking over the task of energy dissipation. The overwhelming disadvantages of varistors are, they tend to age quickly and overheat during operation. This paper looks at the possibility of the application of a macroscopic memristor (MR), not yet available, combined with a spark gap for over-voltage protection purposes. The objective of this analysis is to find the characteristics of the MR suitable for the above purpose, supported by an example according to the IEC 61000-4-5 [23] standard.

An MR is purely a resistive electric circuit element, connected to the circuit through its two pins and has an M memristance value given in unit ohm (Ω). Basically, the value of the M, i.e. R resistance value of the MR increases if current flows through the device in one direction and decreases if it flows in the opposite direction. Memristance value of an MR is determined by its φ flux, i.e. 'voltage history' depending on q electric charge that has flowed through the MR in the past [24], i.e.

$$M(q) = \frac{d\varphi}{dq} \tag{1}$$

Memristors exist now mainly in microscopic scales; thus, educational illustration is only possible in VR. However, like many other initially small electronic devices, versions of the MR with larger dimensions for heavy current purposes will surely appear in the near future. Since this paper and the 3D VR educational material proposes the application of an MR with dimensions and character not yet available, specific features of already existing devices are not taken into account during these analyses, but only the characteristic of an ideal MR; when the current flowing in one direction increases and the opposite current decreases its memristance (resistance) value.

IV. STRUCTURE OF THE OVER-VOLTAGE PROTECTION CONTAINING MR

At the Faculty of Engineering and Information Technology at University of Pécs has been teaching in MaxWhere 3D VR learning environment since 2016. Connecting to VR education, the methodological advice and trainings are provided for the trainers by the VR Learning Center of Széchenyi István University.

This study analyses the operation of the combined over-voltage protection device in practical teaching over-voltage protection. As a first step, students received the following information in 3D VR space in addition to their knowledge of the memristor and other circuit elements and the required over-voltage protection's standards.

The model was proposed at first in [25] , containing a spark gap, a two-directional MR in series to this spark gap and a signal circuit. This combined device is connected, parallel to the protected circuit between working conductors (L1, L2, L3, N conductors) and the protecting earth (PE) conductor. One unit of the proposed protective circuit is shown in Fig. 1. The thin line in the figure encloses the combined device. Because of the dependence of M on charge q, the operation analysis is performed with a current specified in the EMC IEC 61000-4-5 [23] standard.

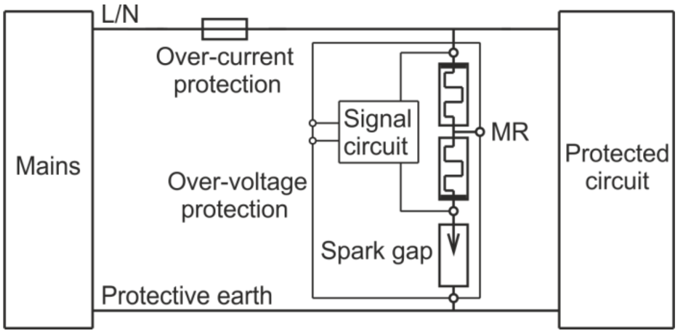

Fig. 2. One unit of the proposed over-voltage protective device

In Fig. 2 apparently two MRs are drawn with their accepted circuit symbol, however, the bidirectional MR applied here can be manufactured, combining two unidirectional MRs in one device with three contacts. This MR has to behave identically in case of any polarity of the current surge. Since a unidirectional current surge influences the M of only one of the internal MRs, their central point has to be connected back to the signal circuit for the regeneration of the MR after its operation.

The signal circuit gives a short voltage signal during the operation of the device. This signal is necessary because the M value of an elementary MR increases during operation and has to be regenerated by a current pulse flowing in the opposite direction than that of the surge current. Because of the significance of the direction of surge current the direction of the signal voltage has to be registered as well.

V. OPERATION OF THE OVER-VOLTAGE PROTECTION

The device is in idle mode, when its MR is having a low M = RL memristance value; when no over-voltage is occurring. This RL idle mode resistance value should set very low; allowing the spark gap to determine the triggering voltage. In case of an overvoltage, the surge current accompanying it increases the M value to a higher M = RH resistance. At the appearance of the over-voltage, the spark gap switches on and the surge current flows through the MR dissipating a part of the energy of the surge. Fig. 3 shows only elements of Fig. 2 (important for illustrating the operation).

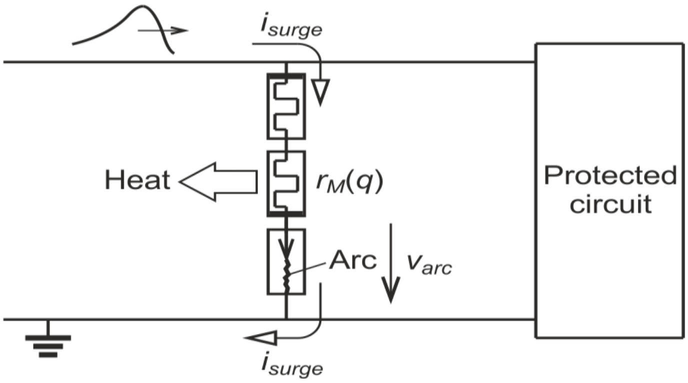

Fig. 3. The device conducting surge current

In Fig. 3 the position of the arrow asymmetrical to the elementary MRs is illustrating heat dissipation. This refers to the fact that, when unidirectional surge current is flowing in a certain direction, it will only have an effect on only one internal MR of the device. Only M of this elementary MR increases and this MR dissipates the majority of the surge energy. After the surge the MR has its higher RH memristance value and a follow-on short-circuit current flows through the device. This follow-on short circuit current is then cut-off by the over-current protection of the protected circuit. The resulting state is shown in Fig. 4.

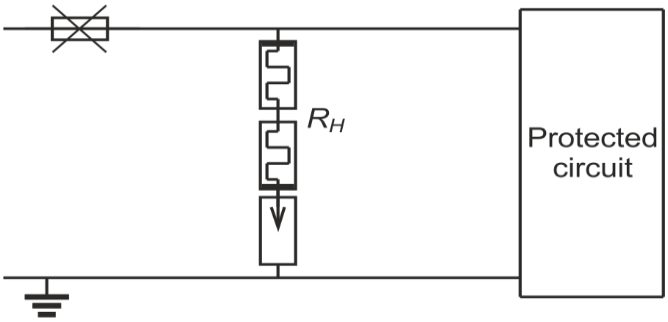

Fig. 4. State of the device after the operation

Operation of the over-current protection does not precede that of the over-voltage protection, because the major part of the surge current flows through within 1 ms and during that time the over-current protection generally does not even begin arcing. The surge current taken into account in this paper is defined by the relevant EMC IEC 61000-4-5 [23] standard and its time function is shown in Fig. 5. For example, the surge current with a peak current value of Ip = 500 A, with a rise time of T1 = 5 μs and half value time of T2 = 350 μs, as defined in [23], is considered.

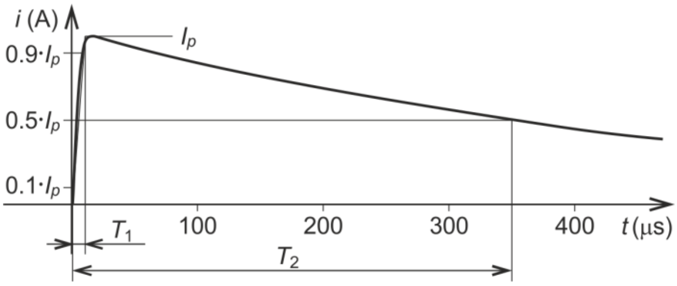

Fig. 5. Characteristic values of a surge current

Time function of the surge current is [23]

$$I(t) = k_i \left(\frac{i_1}{k_{surge}} \cdot \frac{\left(\frac{t}{\tau_1}\right)^{\eta_{surge}}}{1+\left(\frac{t}{\tau_1}\right)^{\eta_{surge}}} \cdot e^{-\frac{-t}{\tau_2}} \right) \qquad (2)$$

with k_i = 31742 A, τ_1 = 1.355 μs, τ_2 = 429.1 μs, i_1 = 0.895, η_{surge} = 1.556 and

$$k_{surge} = e^{-\frac{-\tau_1}{\tau_2}} \cdot \left(\frac{\eta_{surge} \cdot \tau_2}{\tau_1} \right)^{\frac{1}{\eta_{surge}}} \qquad (3)$$

Equations (2) and (3) results in an I(t) current-time function shown in Fig. 6 calculated by the MAPLE mathematical software. Time moment of Imax = 500 A peak current value is tmax = 0.0000151874 s.

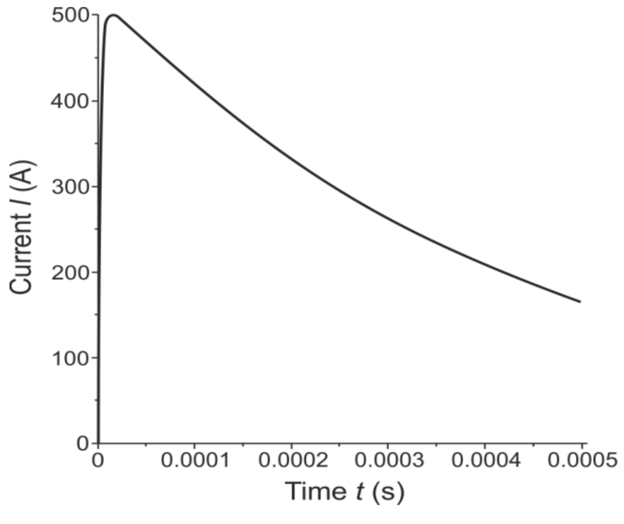

Fig. 6. The current-time function of the surge

Considering the analysis in this paper, the total charge forced through the MR by the surge current is of interest; the amount of which can be calculated with [26]

$$Q_{Surge} = \int_0^\infty i(t)dt = I_p \tau_1 \left(\frac{\tau_1}{\tau_2} \right)^{\frac{1}{\frac{\tau_1}{\tau_2}-1}} \qquad (4)$$

and with the above data

$$Q_{Surge} = 500 \cdot 429.1 \cdot 10^{-6} \left(\frac{429.1}{1.355} \right)^{\frac{1}{\frac{429.1}{1.355}-1}} = 0.2185 \text{ As} \qquad (5)$$

If a category B over-voltage protective device is assumed, then a maximum voltage of V_{max} = 1.5 kV has to be maintained during the surge. Ignoring the resistance of the spark gap, the idle state resistance (low) value of the MR has to be a maximum of

$$R_L = \frac{V_{max}}{I_p} = \frac{1500}{500} = 3\,\Omega \qquad (6)$$

at the moment of maximum current, when the maximum momentary dissipation power is

$$P_{max} = I_p^2 R_L = 500^2 \cdot 0.75 = 750 \text{ kW} \qquad (7)$$

VI. Features of the Applied MR

Generally, the M memristance value of the MR during the surge is not allowed to be higher than

$$M(t) = \frac{V_{max}}{k_i \left(\frac{i_i}{k_{surge}} \cdot \frac{\left(\frac{t}{\tau_1}\right)^{\eta_{surge}}}{1+\left(\frac{t}{\tau_1}\right)^{\eta_{surge}}} \cdot e^{-\frac{-t}{\tau_2}} \right)} \qquad (8)$$

with a starting value of M(t = 0) = RL and finishing value of M(t = tD) = RH, where tD is the surge time and RH is the high-end value of M.

For the desired MR characteristic, the function M(q) is necessary, instead of M(t) and q(t) is the antiderivative of (2) which cannot be solved analytically:

for *i* **to** 100 **do**
Qn[*i*] := *ApproximateInt* (*It*, *t* = tmax..tmax + (i – 1) · 0.000005, output = value);
In[*i*] := *subs* (*t* = tmax + (i – 1) · 0.000005, It);

$$Mn[i] = \frac{V_{max}}{In[i]};$$

end do:

MAPLE operation has been used for the calculation of t time, I current, Q charge, and M memristance values at 100 different time moments between tmax and 500 μs taken into account as end time of the calculation shown also in Fig. 5. During the time period before tmax no change happens in the M value of the elementary MR belonging to the given surge current direction, its value remains R'_L = 1.5 Ω before t_{max}. In the M value of the other elementary MR happens a slight change during the increasing period of the surge current, however, its effect will be neglected in this calculation because this M returns to its original value within a few microseconds during the decreasing period of the surge current. We used Maple as a Mathability [27] for emulating and Enhancing Human Mathematical Capabilities.

Thus as a result of the numerical calculation performed by MAPLE 100 t values – 0.0000151874 s, 0.0000651874 s … 0.00496519 s, 100 I values – 500.015 A, 498.278 A … 161.4141 A, 100 q values – 0, 0.002497 As … 0.150000 As and 100 M values are produced. Q(t) values are plotted in Fig. 7.

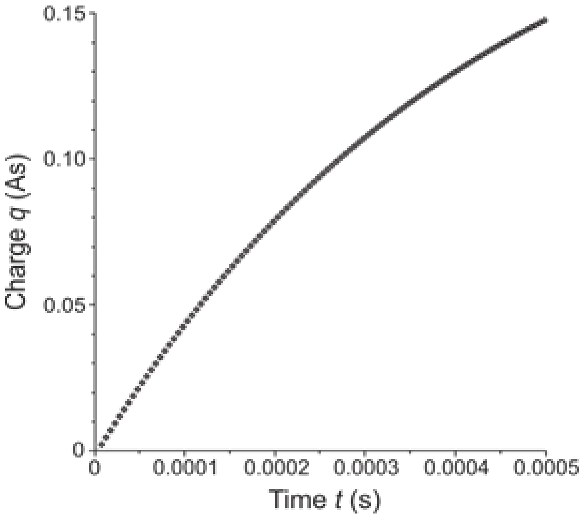

Fig. 7. Q(t) function of the surge

In Fig. 8, current and memristance is shown depending on time. When the surge current has not reached its peak value the total memristance value remains 3 Ω then begins to rise inversely proportionally to current I.

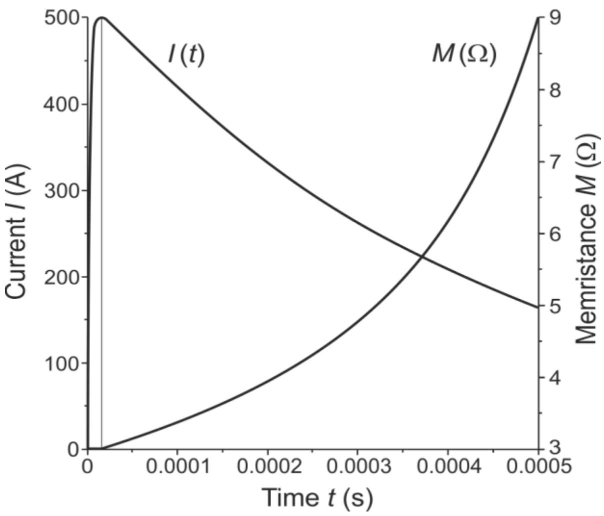

Fig. 8. *I*(*t*) function of the surge and *M*(*t*) function of the MR

Finally, the 100 M values are matched by the software for the 100-time values and the resulted M(q) function of the MR plotted in Fig. 9.

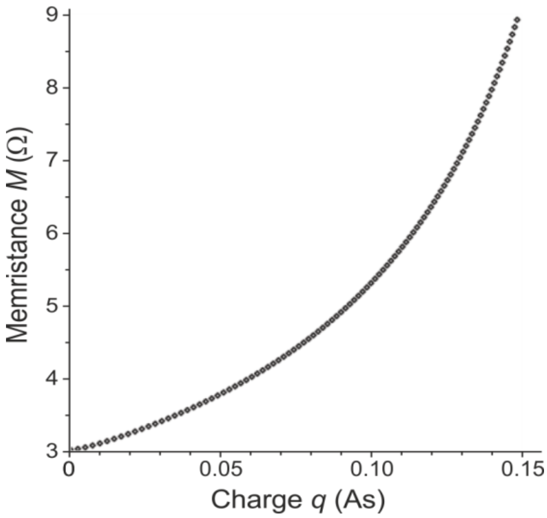

Fig. 9. *M*(*q*) function of the MR

This is the total M(q) characteristic of the MR proposed for over-voltage purposes. This curve is the upper envelope of the actual M(q) characteristic of the MR possibly applied in the practice. However, it has to be taken into account that if the actual curve is lower than the above maximum, then the dissipated energy will be less.

VII. Dissipated Surge Energy

Part of the energy dissipated by the MR is basically calculated with

$$W_{MR} = \int_0^\infty i^2(t) M(t) dt \qquad (9)$$

However, because of the numerical calculation, only a finite time period of the surge is taken into account. Beyond the end of this period, only a negligible part of the energy is not considered. Thus this period lasts from 0 μs to 2 ms as can be seen in Fig. 10.

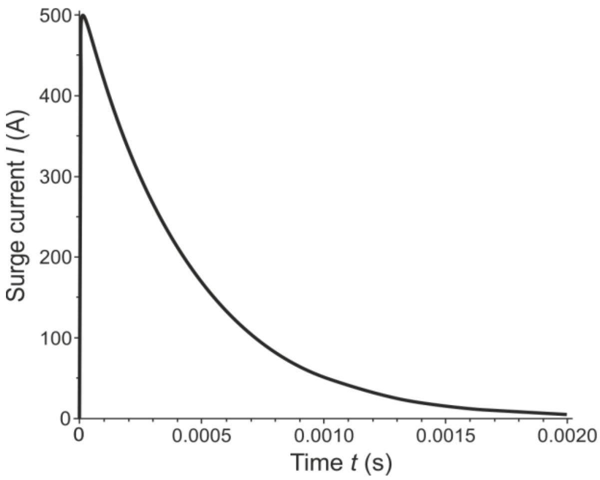

Fig. 10. Complete’ surge current

At 2 ms the current value decreases to 4.953 A, less than 1% of the peak value of 500 A. The summation is performed by the following modified MAPLE cycle:

for *i* **to** 200 **do**

Qn[*i*] := *ApproximateInt* (*It*, *t* = tmax..tmax + (i – 1) · 0.00001, output = value);

In[*i*] := *subs* (*t* = tmax + (i – 1) · 0.00001, It);

$$Mn[i] = \frac{V_{\max}}{In[i]};$$

$En[i] := In[i]^2 \cdot Mn[i] \cdot 0.00001;$

$Em[i] := In[i]^2 \cdot 3 \cdot 0.00001;$

end do:

Sum(*En*[*k*], *k* = 1..200) = *sum*(*En*[*k*], *k* = 1..200).

The energy resulted by the above summation (En[k]) for our example is EMR = 329.56 J. For a comparison to other devices, i.e. voltage-dependent resistors (VDR) being able to dissipate energy connected in series with the spark gap a device, e.g. a varistor, with a maximum resistance value constant in time allowed by the maximum voltage of Vmax = 1500 V is considered. This timely constant resistance value is 3 Ω.

The energy resulted by the summation Em[k] is EVDR = 171.57 J. These results show that an MR with an optimum M(q) characteristic could dissipate nearly twice as much energy from the total surge energy than a VDR with nearly constant resistance during the flow of the surge current. The maximum allowable voltage is not exceeded in the case of the MR and in the case of the VDR; however, in the case of the latter, this voltage appears only for a different time period and in the case of the former for several milliseconds.

VIII. CONCLUSIONS

This paper analyses the possibility of the application of an MR combined with a spark gap for over-voltage protection purposes. Such macroscopic MRs are not yet available, however, their appearances can be expected in the near future. In MaxWhere 3D VR environment the operation of an MR connected in series with a spark gap, both connected in parallel with the protected electric circuit has been analyzed. Thanks to their purely dissipative nature, MRs can dissipate a part of the energy of the surges. An optimum M(q) characteristic of the MR has been proposed for this purpose, supported by an example, on the basis of the IEC 61000-4-5 standard. The optimum M(q) characteristic gives the MR the ability to dissipate, maximum possible energy from the total surge energy.

As a result of this analysis, a monotone increasing M(q) characteristic has been found, which composes the upper envelope of the actual M(q) characteristic of the MR. However, it has to be taken into account that, if the actual curve is lower than the above maximum, then the dissipated energy will be less. Adequate cooling of the MR has to be ensured.

For this numerical example, a characteristic of both the MR and VDR has been chosen so that they could be able to dissipate maximum possible energy. Neglections and idealizations have been applied in 3D VR environment for simplifying the way to the results. 100% of users claimed that the analysis were more effective in 3D VR. They are more effective in multitasking, fast decision-making and highlighting the relevant content in 3D VR spaces. Based on students' feedback we can state that the education of the memristor technologies can be made efficient if the design thinking method is also applied in the VR educational space.

REFERENCES

[1] I. Horváth, Behaviors of Students in 3D VR, In Cognitive Infocommunications (CogInfoCom), 2019 10th IEEE International Conference, Naples, Italy

[2] Small G.W. Vorgan G., iBrain: Surving the technological Alteration of the Modern Mind, Harper Collins, New York, 2008.

[3] László Imre Komlósi, Patrick Waldbuesser, The cognitive entity generation: Emergent properties in social cognition, Cognitive Infocommunications (CogInfoCom), 2015 6th IEEE International Conference on Year: 2015, Pages: 439 - 442, DOI: 10.1109/CogInfoCom.2015.7390633

[4] P. Baranyi, A. Csapo, Gy. Sallai, Cognitive Infocommunications (CogInfoCom), Springer International Publishing Switzerland, p.191.

[5] P. Baranyi and A. Csapo, Definition and Synergies of Cognitive Infocommunications, Acta Polytechnica Hungarica, vol. 9, pp. 6783, 2012. (978-3-319- 19607-7, http://www.springer.com/us/book/9783319196077#aboutBook.

[6] Báint Lampert, Attila Pongrácz, Judit Sipos, Adel Vehrer, Ildikó Horvath: MaxWhere VR-learning improves effectiveness over clasiccal tools of e-learning, Acta Polytechnica Hungarica, pp. 125-147. Vol. 15, No. 3, 2018.

[7] Ildikó Horváth, Anna Sudár: Factors Contributing to the Enhanced Performance of the MaxWhere 3D VR Platform in the Distribution of Digital Information, Acta Polytechnica Hungarica, pp. 149-173. Vol. 15, No. 3, 2018.

[8] Borbála Berki (2018), Better Memory Performance for Images in MaxWhere 3D VR Space than in Website, 9th IEEE International Conference on Cognitive Infocommunications CogInfoCom, pp.283-287.

[9] Borbála Berki (2019), Desktop VR as a Virtual Workspace: a Cognitive Aspect, Acta Polytechnica Hungarica, Vol. 16, No. 2, pp.219-231.

[10] Ildikó Horváth (2019) MaxWhere 3D capabilities contributing to the Enhanced Performance of Trello 2D software, Acta Polytechnica Hungarica Volume 16, Issue Number 6. pp. 55-71. 2019.

[11] Adam Csapo, Ildikó Horváth, Péter Galambos and Peter Baranyi VR as a Medium of Communication: from Memory Palaces to Comprehensive Memory Management In Cognitive Infocommunications (CogInfoCom), 2018 9th IEEE International Conference, Budapest

[12] J. Baranyiné Kóczy, L. I. Komlósi, "Revisiting literacy. Changing learning paradigms in digital culture Argumentum," Debreceni Egyetemi Kiadó, vol 15 pp.117-132. 2019.

[13] E. Fassbender., W. Heiden, "The virtual memory palace," Journal of Computational Information Systems, 2(1), 457-464. 2006.

[14] Kvasznicza, Z. (2017, September). Teaching electrical machines in a 3D virtual space. In Cognitive Infocommunications (CogInfoCom), 2017 8th IEEE International Conference on (pp. 000385-000388).

[15] I. Horváth, Disruptive technologies in higher education, In: Proceedings of 7th IEEE Conference on Cognitive Infocommunications, pp. 347-352. 2016

[16] T. Ujbanyi, J. Katona, G. Sziladi, A. Kovari: "Eye-Tracking Analysis of Computer Networks Exam Question Besides Different Skilled Groups", 7th IEEE International Conference on Cognitive Infocommunications (CogInfoCom), Wroclaw 2016

[17] A. Kovari, J. Katona, C. Costescu. "Evaluation of Eye-Movement Metrics in a Software Debbuging Task using GP3 Eye Tracker," Acta Polytechnica Hungarica, vol 17, no 2, pp. 57-76, 2020.

[18] A. Kovari, J. Katona, C. Costescu. "Quantitative Analysis of Relationship Between Visual Attention and Eye-Hand Coordination," Acta Polytechnica Hungarica, vol 17, no 2, pp. 77-95, 2020.

[19] A. Gilányi, M. Balint, R. Hajdu, S. Tarsoly, and I. Erd˝os, “Presentation of the Church of Zelem´er in the Virtual Collaboration Arena (VirCA),” in 6th IEEE Conference on Cognitive Infocommunications (CogInfoCom). IEEE, 2015, pp. 581–582.

[20] V. Gősi Kövecsesné, The pedagogical Project of Education for Sustainable Development in 3D virtual space, 10th IEEE International Conference on Cognitive Infocommunications, Naples, Italy, 2019.

[21] V. Gősi Kövecsesné, impulse aus wissenschaft, forschung und pädagogischer praxis, Eisenstadt: E. Weber Verlag GmbH, pp 119-124 (2017)

[22] John E. Arnold's creative thinking theories", in Plattner, H.; Meinel, C.; Leifer, L. (eds.), Design thinking research. Making distinctions: Collaboration versus cooperation, Understanding Innovation, Cham: Springer, pp. 13–40

[23] IEC 61000-4-5 Electromagnetic compatibility (EMC) Part 4-5: Testing and measurement techniques – Surge immunity test. Immunity requirements with regard to unidirectional surges covered by over-voltage from switching and lightning transients.

[24] L. Chua, Memristor - the missing circuit element, IEEE Trans. Circuit Theory 18, 507–519, 1971.

[25] [3] G. Elmer, A Possible Application of Memristors for Secondary Lightning Protection, Recent Patents on Electrical and Electronic Engineering, Vol. 8, No. 2, 2015.

[26] [4] M. Rock, Prüfgeneratoren zur Simulation von Blitzimpulsströmen im Labor und ihre Wechselwirkung mit den Prüfobjekten (in German), Universitätsverlag Ilmenau, 2012.

[27] P. Baranyi and A. Gilányi: Mathability: emulating and enhancing humanmathematicalcapabilities, in 4th IEEEInternationalConference on Cognitive Infocommunications (CogInfoCom). IEEE, 2013, pp. 555–558.