SPD RESPONSE TO INTERNAL GENERATED NEUTRAL TO EARTH TRANSIENT IN LOW VOLTAGE SYSTEM

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To my lovely parents Abdul Adzis & Zaliha and parents in law Mohd Saman & Jamaliah, who gave me endless love, trust, constant encouragement over the years, for prayers, and for taking care of our children Zihni and Irfan when we both couldn't make it.

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ABSTRACT

It is essential to have a steady and continuous power supply without halting due to the false triggers to ensure continuity in activities and convenience of users especially when they are dealing with sensitive equipment. It is also vital to protect the sensitive equipment from disturbance to ensure maximum lifespan. In this country, the awareness of protecting sensitive equipment from premature malfunction due to surge overvoltage is increasing with the use of widely implemented Surge Protective Device (SPD). In reality, besides atmospheric surge overvoltage, another surge namely neutral to earth transient is also threatening sensitive equipment and cause nuisance Residual Current Device (RCD) tripping if the magnitude of the overvoltage exceeds a specific figure. The neutral to earth transient is a low magnitude transient that can go up to 250 V. Factors known to contribute to the neutral to earth transient event is related to load switching activities and wiring problems. However, this kind of disturbance is less considered in low voltage distribution system although the frequency of the occurrence isliterally higher than atmospheric overvoltage. In this research, the characteristic of typical SPD circuit under the presence of neutral to earth transient is analysed to ascertain its capability in diverting the impulse voltage. Also, to understand the operation of the voltage-limiting device in the presence of surge. The analysis has been carried out by modelling and simulating the typical SPD circuit using Microcap software. The typical SPD circuit was simulated by applying 6 kV lightning impulse voltage of 1.2/50 μs, and neutral to earth impulse voltage of 1.2/20 ms from 250 V to 750 V. The 250 V input voltage represents the neutral to earth transient. The purpose of simulating the other two input voltage is to observe the behaviour of the protective clamping device in the presence of different surge level. The output voltage has been measured, and it is found that the SPD cannot clamp the 250 V neutral to earth transient. Therefore a hybrid surge protection circuit is proposed to limit the low amplitude neutral to earth transient. The proposed surge protection circuit can limit both normal mode (L_N) and common mode (L-E, N-E) transient.

ABSTRAK

Kuasa elektrik yang stabil tanpa gangguan adalah satu keperluan untuk memastikan aktiviti penting dapat dilaksanakan bagi keselesaan pengguna terutamanya sewaktu sedang menggunakan peralatan yang sensititif. Perlindungan ke atas peralatan yang sensitif kepada gangguan juga adalah penting bagi memastikan jangka hayat yang maksima. Di negara ini, kesedaran untuk melindungi peralatan yang sensitif kepada gangguan arus/voltan pusuan semakin meningkat dengan memasang Alat Pelindung Arus Pusuan. Namun realitinya selain arus/voltan pusuan disebabkan keadaan semulajadi, terdapat satu lagi voltan pusuan dikenali sebagai voltan pusuan neutral ke bumi yang mengancam peralatan sensitif dan menyebabkan Pemutus Litar Bocor ke Bumi terpelantik jika nilai voltan melebihi had tertentu. Voltan pusuan neutral ke bumi adalah sejenis voltan pusuan bervoltan rendah yang mana nilainya sehingga 250 V. Faktor-faktor yang menyebabkan berlakunya voltan pusan neutral ke bumi adalah aktiviti pensuisan beban dan masalah pendawaian. Walaubagaimanapun, gangguan ini jarang mendapat perhatian dalam sistem kuasa voltan rendah walaupun kadar kekerapannya lebih tinggi dari arus/voltan pusuan yang disebabkan oleh keadaan semulajadi. Dalam kajian ini, sifat litar Alat Pelindung Arus Pusuan di analisa untuk memastikan keupayannya untuk menghadkan arus pusuan ini. Selain itu, kajian ini bertujuan untuk memerhati dan memahami operasi komponen pelindung sewaktu kehadiran voltan pusuan. Analisa telah dibuat dengan merekabentuk model litar dan membuat simulasi menggunakan perisian Microcap. Litar Alat Pelindung Arus Pusuan telah disimulasi dengan masukan 6 kV voltan pusuan 1.2/50 μs dan masukan neutral ke bumi voltan pusuan 1.2/20 ms dari 250 V ke 750 V. Masukan voltan pusuan 250 V mewakili pusuan neutral ke bumi. Tujuan membuat simulasi bagi dua kadaran lagi adalah untuk memerhatikan sifat komponen pelindung sewaktu kehadiran beberapa nilai voltan pusuan. Voltan keluaran diukur dan didapati Alat Pelindung Arus Pusuan tidak boleh mengapit voltan pusuan masukan 250 V neutral ke bumi. Oleh itu, satu litar Alat Pelindung Arus Pusuan baru telah dicadangkan untuk menghadkan voltan pusuan neutral ke bumi. Litar ini boleh menghadkan kedua-dua pusuan dari kilat dan juga dari neutral ke bumi.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
CBMA	-	Computer and Business Equipment Manufacturers Association
DB	-	Distribution Board
ELR	-	Earth Leakage Relay
IEEE	-	Institute of Electrical and Electronic Engineers
IEC	-	International Electrotechnical Commission
ITIC	-	Information Technology Industry Council
L-N	-	Line to Neutral
L-E	-	Line to Earth
MCOV	-	Maximum Continuous Operating Voltage
MOV	-	Metal Oxide Varistor
MSB	-	Main Switchboard
N-E	-	Neutral to Earth
PRCD	-	Portable Residual Current Device
RCBO	-	Residual Current Circuit Breaker with Overcurrent Protection
RCCB	-	Residual Current Circuit Breaker
RCD	-	Residual Current Device
SLG	-	Single Line to Ground
SPD	-	Surge Protective Device
SRCD	-	Socket-outlet incorporating an RCD
TN-C	-	Terre Neutral Combined
TN-C-S	-	Terre Neutral Combined Separate
TN-S	-	Terre Neutral Separate
TT	-	Terre Terre

LIST OF SYMBOLS

V	-	Volt
kV	-	Kilovolt
μs	-	Microsecond
ms	-	Millisecond

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The quality of power in a commercial building is paramount to ensure satisfying operation of equipment especially electronic (non-linear) equipment that dominates most of the stuff in many parts of the world for decades ago. It is also essential to have a steady and continuous power supply without halting due to the false triggers to ensure continuity in activities and convenience of users. Disturbances in the power supply that is not due to a real electrical fault can cause inconvenience and significant loss. The most threatening disturbance that commonly effects electronic equipment is transient due to lightning and switching effect. In the recent years, those two troubles are the primary concern of the manufacturers and the users of electronic equipment [1].

The lightning transient enters the service entrance through several ways including inductive coupling and direct coupling. The capacitor bank energisation, ferroresonance and transformer energisation (to name a few) produce switching transient in the electrical system [2]. The lightning and switching transients are usually of high amplitude and energy. The standard method utilised to protect sensitive equipment from lightning and switching overvoltage in low voltage system is surge protective device (SPD) [3]. Surge protective device is a power conditioner between supply and load intended to suppress transient from entering power system and the load. The primary purpose of SPD in low voltage system regardless of supply system configuration (TT, TN-C, TN-C-S and TN-S) is to divert both normal mode (L-N) and common mode (L-E, N-E) transient to the ground [4].

Not many are aware of the existence of another transient that occurs between neutral to earth. The consequence of the transient is as harmful as the effect of the lightning and high energy switching transient. The transient is generated internally and a part of everyday operation. The transient leads to nuisance tripping of the residual current device (RCD) and damage to electronic equipment. In 2008, Mohd. Zaki Abdullah [5] observes that RCD nuisance tripping occurs when neutral to earth transient higher than 160 V. In 2013, Mohd Zaki Abdullah et. al [6] conducted on-site analysis and discovered that high leakage current from equipment plus high neutral to earth voltage is the main reason for RCD nuisance tripping and equipment damage. In 2014, Roldán-Porta et. al [7] reporting the event of RCD nuisance tripping due to neutral to earth transient in a hospital in Spain that happened at day one of operation. Escrivá-Escrivá et. al [8] continues to discuss this issue in another journal published in 2016.

1.2 Problem Statement

Neutral to earth transient is a switching transient (internal load switching) that produces an intermittence single line-to-ground fault (SLG) in the same electrical distribution system. The amplitude of the neutral to earth transient can go up to 250 V for a duration of 20 ms [6]. The equipment that damaged due to neutral to earth transient is typical non-linear office equipment such as computers, facsimile and copying machine [6][7] even though the equipment is required to equip with internal surge protection circuit according to [9]. The question that is lingering around as to why the transient can passes through the SPD or internal surge protection circuit without being clamped.

There are misconceptions about the capability of SPD in limiting surge overvoltage. Prolong confusions could lead to unresolved issues. According to [10], SPD is used to protect electrical system and equipment against various overvoltage and impulse currents such as lightning and switching surge. In a typical design of electrical distribution system, SPD is usually installed at least one at main switchboard (MSB) to limit transient overvoltage and divert surge current coming from outside facility to protect system and load. SPD can also be installed as close as possible to the load to protect sensitive equipment. This type of SPD is known as SPD Class III and it usually located at distribution board (DB). The capability of SPD to limit transient overvoltage specifically for voltage-limiting type SPD is dependent on the rating of maximum continuous operating voltage (MCOV). According to [11], the minimum rating for MCOV at neutral to earth shall be equal to or higher than 230 V. The specification of a varistor; the voltage-limiting component assembled inside SPD with MCOV rating at 230 V (for a specific brand), gives a clamping voltage of 595 V. Further studies of the varistor data sheet provide the conclusion that higher rating of MCOV (more than 230 V) offers higher clamping voltage, while a lower rating of MCOV (less than 230 V) gives lower clamping voltage. In practice, the rating of MCOV for SPD Class III at neutral to earth varies from 255 V to 280 V [12].

It is essential to observe the response of the typical SPD circuit in limiting neutral to earth transient to establish an understanding on its operation and the relationship between maximum continuous operating voltage and maximum clamping voltage of the protective component (measured limiting voltage or let-through voltage). The comprehension can be used to improve the surge protection circuit so that a broad protection range can be proposed to prevent the neutral to earth transient from disturbing power supply operation (from RCD nuisance tripping) and to increase the susceptibility of equipment (from equipment damage).

1.3 Research Objective

The purpose of this research is to study and observe the response of typical SPD circuit to the internal generated neutral to earth transient in low voltage system regarding limiting voltage or let- through voltage. The specific objectives of this project are as follow:

1. To simulate a typical SPD circuit by injecting high amplitude and low amplitude input impulse voltage and measure its limiting voltage.

2. To propose a hybrid surge protection circuit designed for neutral to earth protection mode to improve SPD response to switching transient.

3. To compare the limiting voltage of proposed hybrid surge protection circuit with typical SPD circuit when injected with low amplitude input voltage.

1.4 Scope of Work

The scopes and limitation of work in this project are:

1. Study the value of maximum continuous operating voltage (MCOV) and voltage protection level of available commercial SPD Class III in the market.

2. Design two surge protection circuits by using Microcap software based on the typical value of MCOV and definition of SPD as defined by IEEE, MS IEC, IEC and BS to observe their response regarding limiting voltage. The SPD circuit is based on a single nonlinear voltage-limiting device according to [3].
   i) Typical SPD circuit
   ii) Proposed hybrid surge protection circuit

3. The simulation for both circuits accomplished by using Microcap software. The waveform parameter of the input voltage for high amplitude is as defined by IEEE, MS IEC, IEC and BS (positive waveform only) while waveform parameter for low magnitude is based on captured data in previous research.

4. Both circuits are designed based on protection mode at neutral to earth only.

5. The technology of the clamping device for both circuits is Metal Oxide Varistor (MOV).

1.5 Research Contribution

This research is vital because it highlights the occurrence of low amplitude neutral to earth transient in low voltage system that is less considered compared to other transients. Although it is a low magnitude transient, it does affect the system and load. The most apparent effects of the transient are RCD nuisance tripping and equipment damage. This research is significant because it studies the response of SPD concerning limiting voltage when simulated with neutral to earth transient. The purpose is to ascertain the ability of SPD to give protection against this transient, as it is the only protection device used to protect sensitive equipment from lightning and switching transient. This research proposes a new method to limit the transient by suggesting a hybrid surge protection circuit that can provide a broad protection range for switching transient.

1.6 Project Report Organization

This thesis consists of five chapters. The description of each section is as follows:

Chapter 1: Provides overview and background of research, objectives, scope and contribution of the research.

Chapter 2: Gives details on the literature review on the supply system configuration, event of neutral to earth transient and the detailed topology of surge protection device.

Chapter 3: Discusses the research methodology adopted in this project and details procedure of project implementation.

Chapter 4: Discuss and analyse the results of the simulation.

Chapter 5: Concludes and summarise the findings and recommendation for future work.

REFERENCES

[1] IEEE Standard, *Recommended Practice for Powering and Grounding Electronic Equipment*. IEEE 1100-2005.

[2] IEEE Standard, *Recommended Practice for Monitoring Electric Power Quality*. IEEE 1159-2009.

[3] IEC Standard, *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems-Requirements and test methods*. IEC 61643-11: 2011.

[4] Gomes, Chandima, and Vernon Cooray, 2010, "Surge protection of low voltage systems and relevant standards”, *30th International Conference on Lightning Protection-2010, Cagliari, Italy,* pp 1-8.

[5] Mohd Zaki Abdullah, 2008, “Recent Advances in Electrical Earthing System”, *Journal of Engineering Science,* vol 4, no. 3.

[6] Abdullah, M.Z., Ariffin, R., 2013, “Power Quality Analysis of Residual Current Device (RCD) Nuisance Tripping At Commercial Buildings,”*IEEE Symposium on Industrial Electronics & Applications,* pp. 122-125.

[7] Roldán-Porta, C., Escrivá-Escrivá, G., Cárcel-Carrasco, F.J, and Roldán-Blay, C., 2014,“Nuisance tripping of residual current circuit breakers: A practical case”, *Electric Power Systems Research*, vol 106, pp. 180-187.

[8] Escrivá-Escrivá, G., Porta, C.R., and de Jong, E.C.W.,2016, “Nuisance tripping of residual current circuit breakers in circuits supplying electronic loads”, *Electric Power Systems Research*, vol. 131, pp. 139-146.

[9] British Standard, *Information technology equipment – Safety Part 1: General Requirements*. BS EN 60950-1:2006+A2:2013.

[10] British Standard, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selections and application principles*. DD CLC/TS 61643-12: 2009.

[11] Malaysian Standard, *Electrical Installations of Buildings-Part 5-53: Selection and Erection of Electrical Equipment – Isolation, Switching and Control.* MS IEC 60364-5-53:2003.

[12] Electrical Material Approved List. Available from: <www.jkr.gov.my/jmal> [1 October 2017].

[13] Dahari M. Siran, 2011, "Residual Current Devices in Electrical Installation", *National Conference on Electrical Safety*. Available from: < https://www.st.gov.my/>.[11 December 2017].

[14] IEC Standard, *Residual current operated circuit breakers without integral overcurrent protection for household and similar uses (RCCBs) – Part 1: General rules*, IEC 61008-1:2013.

[15] Dalila Mat Said, *Power Quality*, lecture notes distributed in Power Quality MKEP1563 at Universiti Teknologi Malaysia, on semester 2 2016/2017.

[16] Gomes, C., 2011, "On the selection and installation of surge protection devices in a TT wiring system for equipment and human safety," *Safety Science*, vol. 49, no. 6, pp. 861-870.

[17] IEEE Standard, *Guide for The Application of Surge Protective Device For Use on the Load Side of Service Equipment in Low Voltage (1000V or less, 50Hz or 60 Hz) AC Power Circuit.*

[18] Amizah Mohd. Ariffen, 2011, *Development of Class II and Class III Surge Protective Device for Low Voltage Protection System*. Master Thesis, Universiti Putra Malaysia.

[19] Ariffen, A.M., Kadir, M. and Ahmad, W., 2011. The Development of Hybrid Surge Protection Circuit with Effect of Adding a Filter. *International journal of engineering & technology*, vol. 11, no. 2, pp.38-47.

[20] Technical Data Sheet, *EPCOS Leaded Varistors*. Available from: <http://www.farnell.com/datasheets>. [1 September 2017].

[21] IEC Standard, *Electromagnetic Compatibility Part 4-5: Testing and Measurement Techniques – Surge immunity test*. IEC 61000-4-5:2005.

[22] Simulating a surge pulse. Available from: <https://www.electronicspoint.com/resources/simulating-waveforms.16>. [28 September 2017].

[23] IEC Standard, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and test*. IEC 60664:2007.

[24] Beutel, A. and Van Coller, J., 2005. The application of silicon avalanche diodes on low-voltage power systems. *IEEE transactions on industry applications*, vol. 41, no. 4, pp.1107-1112.

[25] Technical Data Sheet, *ST 1.5KE*. Available from: <http://www.st.com>. [1 September 2017].

[26] Shafie, M. A., Singh, H., & Rahman, M. A., 2010, “Harmonic and neutral to ground voltage reduction using isolation transformer”, *Power and Energy (PECon), 2010 IEEE International Conference,* pp. 561-566.

[27] Czapp, S., Dobrzynski, K., Klucznik, J. and Lubosny, Z., 2017, June. Low-frequency tripping characteristics of residual current devices. In *Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), 2017 IEEE International Conference,* pp. 1-4.

[28] Xiang, Y., Cuk, V. and Cobben, J.F.G., 2011, May. Impact of residual harmonic current on operation of residual current devices. In *Environment and Electrical Engineering (EEEIC), 2011 10th International Conference on*, pp. 1-4.

[29] Khanmiri, D.T., Ball, R. and Lehman, B., 2017. Degradation Effects on Energy Absorption Capability and Time to Failure of Low Voltage Metal Oxide Varistors. *IEEE Transactions on Power Delivery*, Vol. 32, no.5, pp.2272-2280.

[30] Paul, D., 2001. Low-voltage power system surge overvoltage protection. *IEEE Transactions on Industry Applications*, Vol. 37, no.1, pp.223-229.

[31] Cai, L., Wang, J., Cheng, S., Yang, S., Li, B. and Zhou, M., 2011, November. SPD response characteristics in nature lightning. In *Lightning (APL), 2011 7th Asia-Pacific International Conference,* pp. 741-745.

[32] Li, H., Xu, N., Chen, W. and Brocke, R., 2014, October. Advanced requirements on SPDs protecting sensitive equipment. In *Lightning Protection (ICLP), 2014 International Conference*, pp. 1206-1211.

[33] Khanmiri, D.T., Ball, R., Mosesian, J. and Lehman, B., 2016, March. Degradation of low voltage metal oxide varistors in power supplies. In *Applied Power Electronics Conference and Exposition (APEC), 2016 IEEE*, pp. 2122-2126.

[34] Finis, G., Wetter, M. and Meyer, T., 2016, September. New spark-gap technology with efficient line-follow current suppression for the protection of

powerful LV distribution systems. In *Lightning Protection (ICLP), 2016 33rd International Conference on*, pp. 1-7.

[35] Nasiopoulou, C. and Pyrgioti, E., 2012, September. Performance of surge arresters in a low voltage distribution system. In *Lightning Protection (ICLP), 2012 International Conference on*, pp. 1-6.

[36] Barbosa, C.F., Pomponi, R. and Tommasini, R., 2010, September. SPD characteristics for equipment protection. In *Lightning Protection (ICLP), 2010 30th International Conference* pp. 1-8.

[37] Hotchkiss, R.W. and Mikesell, P.E., 2013, July. SPDs shown to improve the reliability of medical equipment—A case study. In *Power and Energy Society General Meeting (PES), 2013 IEEE*, pp. 1-5.

[38] Gomes, C. and Cooray, V., 2010, September. Transients that may affect low voltage electrical systems. In *Lightning Protection (ICLP), 2010 30th International Conference*, pp. 1-13.