Reducing Conducted Emission in EMC Measurement of Smart Street Lighting

Hardiles, Tri Desmana Rachmildha, Deny Hamdani
School of Electrical Engineering and Informatics, Bandung Institute of Technology, Bandung, Indonesia
Email: hardi.1201@gmail.com, trides@konversi.ee.itb.ac.id, deny@ power.ee.itb.ac.id

Wisnu Ananda, Seto Ayom Cahyadi
Center for Material and Technical Product (B4T), Ministry of Industry, Bandung, West Java, Indonesia
Email: ananda@kemenperin.go.id, setocahyadi @kemenperin.go.id,

***Abstract* — Street lighting is an important facility needed to support traffic and environmental security, regional orientation, city accessories, economic activities, and people's mobility at night. Nowadays automation of the street lighting or smart street lighting is applied to save energy consumption. However, the use of smart street lighting can cause electromagnetic emission which at a particular level can interfere with other equipment around it and cause them not to work optimally. This research observed the conducted emission of smart street lighting by applying three different treatments to the sample. The test method used for the measurement refers to CISPR 15:2013 standard. The results showed the value of 49.98 dBuV when no treatment applied, 48.88 dBuV with a rearrangement of the cable connecting remote terminal unit (RTU) to LED lamps, and 48.73 dBuV with the addition of ferrite absorber.**

***Index Terms* — smart street lighting, electromagnetic compatibility (EMC), conducted emission (CE), ferrite absorber**

I. Introduction

Today the urban service and system have led to smart cities. Increased data collection, service-oriented applications, and data analysis will be driven to create new economic services and business opportunities [1]. One of the innovations implemented in the urban system is smart street lighting which becomes a platform for a range of smart city applications [2]. Energy saving is the primary purpose of smart street lighting. The other advantages of the system are remote fault detection, full supervision, critical situation management, removing extra cables, and reduction in maintenance cost [3]. The smart street light has infrastructure at least data collection sensors, LED luminaires (can be dimmed), and communication technology [1]. The smart system in a street light can generate and emit unwanted electrical signals, called electromagnetic noise or pollution, which can interfere with other equipment or systems [4].

The quality performance of the product depends on its compliance with the required standard. Product performance may decrease due to unintended factors occurred due to product design. One of the factors is electromagnetic phenomena. Conducted emission (CE), one of the electromagnetic interference (EMI), is noise emitted over conductive media. The conducted emission measures the electric field in dBμV unit [5][6]. Electromagnetic pollution introduced by line-connected power electronics equipment can radiate by propagating through the power line or using near-field and far-field radiation [7]. This study aims to observe the methods to reduce conducted emission in EMC measurement of smart street lighting.

II. Literature Review

A. Standard

International Special Committee on Radio Interference (CISPR) is a standard that is widely used in EMC testing. The CISPR 15:2013 standard sets limits on conducted and radiated emission testing for electrical lighting and similar equipment [8][9]. The limits for the disturbance voltage (conducted emission) at mains terminals can be seen in Table 1.

B. Conducted Emission

The electrical or electronic device can cause an electromagnetic noise and conduct into the power supply. Therefore it is essential to isolate that electromagnetic noise and other disturbances. The line impedance stabilization network (LISN) is used to get standard impedance and filter out any incoming noise on the main power supply to get clear power for equipment under test (EUT) placed between the power supply and the EUT [7][8].

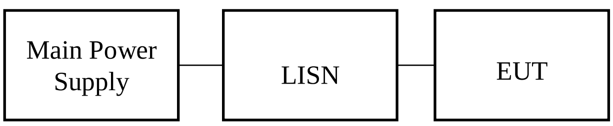

Figure 1. Block diagram for conducted emissions measurement setup.

Manuscript received July 6, 2018; revised March 16, 2019.

doi: 10.18178/ijmerr.8.3.466-471

TABLE I. DISTURBANCE VOLTAGE LIMITS AT MAINS TERMINALS [8][9][10].

Frequency Range	Limits dB(μV)[a]	
	Quasi-peak	Average
9 kHz to 50 kHz	110	-
50 kHz to 150 kHz	90 to 80[b]	-
150 kHz to 0.5	66 to 56[b]	56 to 46[b]
MHz	56[c]	46[c]
0.5 kHz to 5 MHz	60	50
5 MHz to 30 MHz		

[a] At the transition frequency, the lower limit applies.

[b] The limit decreases linearity with the logarithm of the frequency in the range 50 kHz to 150 kHz to 0.5 MHz.

[c] For electrodeless linearity lamps and luminaries, the limit in the frequency range of 2.51 MHz to 3.0 MHz is 73 dB(μV) quasi-peak and 63 dB(μV) average.

C. Mitigation Technique with Ferrite Ring Impedance

The permeability of the ferrite ring (μ), inductance, and frequency are components that can influence the impedance value. The other component is the dimension of the ferrite ring which consists of *D* (outside diameter), *l* (length), and *d* (inside diameter), as shown in Fig. 2a. The equivalent circuit of the ferrite ring is shown in Fig. 2b. The *R(f)* and *L(f)* are frequency resistance and inductance respectively [9][11][12].

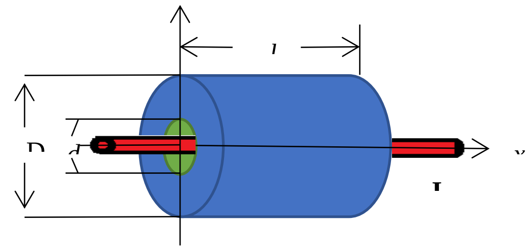

Figure 2a. Illustration of a ferrite ring: the geometry [9][10][11].

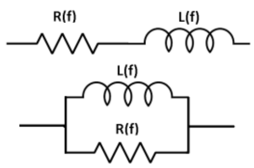

Figure 2b. Illustration of a ferrite ring: the serial and parallel equivalent circuits [9][11][12]

The permeability of ferrite is varied as a function of frequency in the form of a complex number which consists of a real and an imaginary part. Equation 1 is for the series equivalent circuit, and Equation 2 describes the parallel equivalent circuit [9][11][12]. The real and imaginary parts of the permeability, μ' and μ", are applied to both of the equations.

$$Z(f) = j\omega L(\mu' - j\mu") \quad (Ohm) \tag{1}$$

$$Z(f) = \omega L(\mu'.\mu) \,/\, (\mu' - j\mu") \quad (Ohm) \tag{2}$$

Equation 3 defines the inductance (L) of the ferrite ring in Henry unit [12]. The ferrite inductance depends on the current flowing through the wire conductor inside the ferrite ring. The impedance value is proportional to the current. The ferrite impedance will be zero if there is no current flowing to the circuit.

$$\mathrm{L} = \frac{1}{4\pi}\int_0^1 \int_{\frac{d}{2}}^{\frac{D}{2}} (\mu' - j\mu")\left(\frac{\mathrm{l-x}}{\sqrt{y^2-(l-x)^2}} + \frac{\mathrm{x}}{\sqrt{y^2+x^2}}\right) dy\, dx \tag{3}$$

where μ' is the real part of permeability and μ" is the imaginary part of permeability [9][11][12].

D. Mitigation Technique with Rearranged Cable

The cable bundle impedance can affect the EMI measurement results significantly. It depends on the relationship between the cable bundle impedance and the wire impedance [13]. The resonant frequencies of the system can be shifted by the presence of a cable bundle. The critical factor at frequencies near these resonances is cable bundle impedance. Unfortunately, the maximum radiation and the highest current generally occur at frequencies near resonance [14]. The equation of impedance input is given by

$$\mathrm{Zin} = \mathrm{j}\, Z_0 \tan \beta\, \mathrm{l} \tag{4}$$

where

$$Z_0 = \frac{1}{\pi}\sqrt{\frac{\pi}{\varepsilon}}\, cosh^{-1}\frac{s}{d}$$

s = center to center cable separation;
d = cable diameter;
β = phase constant.

The permeability and permittivity of free space can be used for ε and μ in this model although slightly different values (depending on properties of the cable insulation) may be more compatible for a tightly bundled cable. The equation function for the overall lumped impedance of a cable bundled with

$$Z_{bundle} = j\, N^{\alpha}\, \frac{1}{\pi}\sqrt{\frac{\mu}{\varepsilon}}\, cosh^{-1}\frac{s}{d}\, tan\beta l \tag{5}$$

The relative amount of coupling between the "loops" influence the value of α. The value of α near one if flat cable bundles with relatively insignificant inter-loop coupling, while the value of α approaching two if the cable is more tightly bundled.

The method-of-moments of the numerical electromagnetic analysis techniques can be used to solve a variety of EMI problems. When the cable currents dominate the EMI, these techniques are mainly can be used effectively [15][16].

Fig. 3 illustrates the configuration of a similar loosely bundled cable that readily analyzed. A moment-method analysis of this configuration is useful because it correctly accounts for the loss due to cable resistance and radiation and the inter-loop coupling.

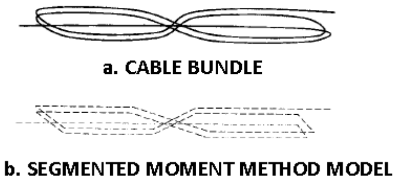

Figure 3. Moment-method cable bundle model [14].

III. METHODOLOGY

The experiments were conducted in the Electronic and EMC Laboratory, Center for Material and Technical Product, Ministry of Industry, Indonesia. The laboratory has the 3-meter Semi-Anechoic Chamber (SAC) and all equipment needed for doing this research. The laboratory has been accredited for ISO/IEC 17025:2005 (The quality standard for testing and calibration laboratories) in EMC luminaires testing.

A. Equipment

The standard requirement for measuring receivers in EMC measurement is explained in CISPR 16-1-1 [17]. The CISPR 16-1-2 defines the ancillary equipment for conducted emission measurement [18].

The LISN is the first main apparatus as shown in Fig.4. The brand is EMCO with model 3816/2 and has a working frequency from 9 kHz until 30 MHz.

The EMI Test Receiver from Rohde&Schwarz (RS) with model ESCI is the second apparatus needed. The Test Receiver is used to produce the average, peak, and quasi-peak value [17].

Pulse Limiter from RS with model ESH3-Z2 is the third apparatus, and it has a working frequency from 9 kHz until 30 MHz. The input attenuator, preamplifier, preselection filter, or input mixer can be destroyed if the measurements are performed on devices with very high pulse energy or pulse spectral density. Pulse Limiter is used to protect the receiver input circuit from transients such as surge pulse and high voltage switching[19]. The requirement for using Pulse Limiter to provide signals of maximum receiver input level without creating nonlinear effects is defined by CISPR 16-2-1 standard [17].

Figure 4. LISN from EMCO.

Figure 5. EMI Test Receiver and Pulse Limiter.

The last apparatus used is the computer and software controller. EMC32 from RS is the software used. Correction factors which influence the measurement such as cable attenuation and transducer or LISN value should be input in the software [20][21].

B. Procedure

Fig. 6 illustrates the experimental setup of CE measurement. The receiver needed warmup time for 30 minutes before starting the measurement. After that, connect the Pulse Limiter to the Receiver. Then, connect the coaxial input cable to the Pulse Limiter. Next, connect the other end of that coaxial cable to the LISN. After that, the power supply of the LISN could be connected to the grid. The last step is to execute the measurement by running the EMC32 software.

The process sequence of CE testing in the software is started by searching for the emission's peak value by sweeping of line phase. After that proceed with sweeping of neutral phase less than 30 seconds. Then measured the quasi-peak value by doing scanning of line phase followed with a neutral phase less than 30 minutes. The next process generated a table and a graph showing the final quasi-peak and the average value. These values then compared with limit from the appropriate CISPR standard depends on the EUT. In the experiments, a smart street light was used as the EUT. Hence the limit in CISPR 15 [20] standard was applied.

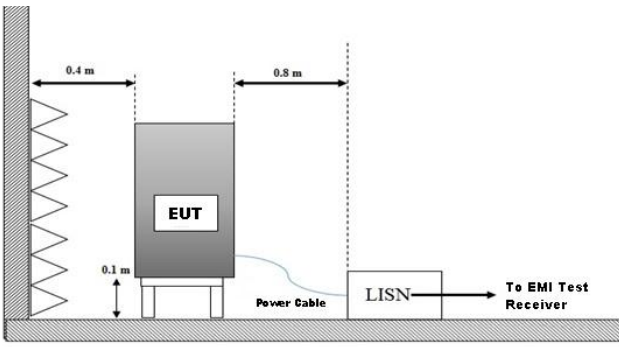

Figure 6. Conducted emission measurement setup diagram.

Based on EMC standards, average and quasi-peak peak limit value are used. However, the more critical value is the quasi-peak limit. The principle of the quasi-peak detector in EMC measurement is like a peak detector followed by a lossy integrator [8].

CE measurement unit is dBµV. Most of EMC measurements use decibel because an emission situation often faces a huge dynamic range, so a logarithmic scaling is more convenient than a linear one [22]. The volt unit is much too large when dealing with emission testing so that the measurement testing uses µV unit [22].

In this research, the CE measurement of smart street lighting is divided into three kinds. The first one is the basic one as a baseline. The second one is by using cable treatment technique. The last one is by placing a ferrite absorber upon the rearranged cable.

For the basic CE measurement, a smart street light as EUT was installed and turned on, then connect the other end of the coaxial cable to the LISN. The EUT's mains cable should be connected first to the EUT port of LISN before connecting the LISN to the grid. Smart street lighting is classified as table-top equipment. Thus according to CISPR 15 standard, a non-metallic table, preferably made from wood, with height 40 cm was used to place the EUT [23]. The distance between EUT and LISN is preferable to be at 80 cm. Fig. 6 shows the setup of basic CE measurement.

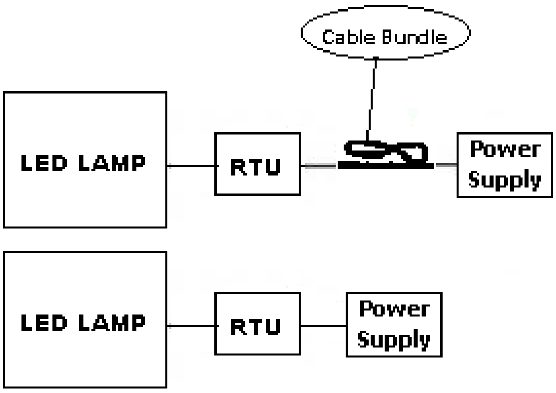

Figure 7. CE measurement with rearranged cable.

With the same measurement procedure, the CE measurement with rearranged cable schematic diagram is shown in Fig. 7. The initial condition is the cable between Remote Terminal Unit (RTU) and the power supply is too long. By rearranging the cable, the effect of the measurement result was observed.

The use of ferrite absorber is one of the main suppression methods for the conducted emissions coming from the supply network [24][25]. The effectiveness of this reduction method was demonstrated by placing a ferrite absorber between the RTU and power supply as shown in Fig. 8.

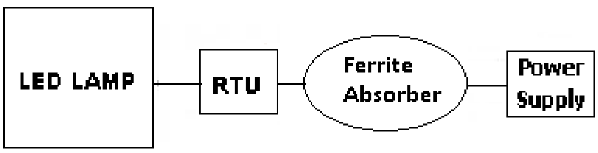

Figure 8. CE measurement with rearranged cable and the addition of a ferrite absorber.

IV. Result and Discussion

A. Basic CE Measurement

Fig. 9 portrays the full spectrum graph of basic CE measurement. The picture points out three highest average values, denoted by the green diamonds. The solid purple line indicates the average limit of CISPR 15. The highest average value is 49.98dBµV at 0.43 MHz.

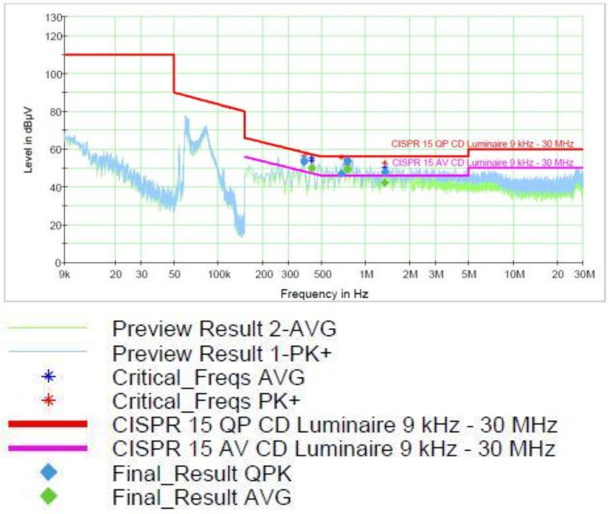

Figure 9. Full spectrum graph of basic CE measurement.

B. CE Measurement with Rearranged Cable

Fig. 10 shows the full spectrum measurement from smart street lighting with cable treatment. The graph points out four highest average values, denoted by the green diamonds. The highest average value of the measurement is 48.88 dBµV at 0.42 MHz.

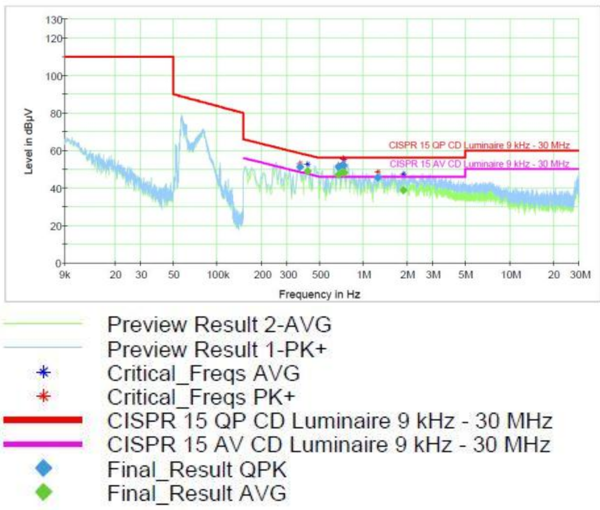

Figure 10. Full spectrum graph of CE measurement with rearranged cable.

C. CE Measurement with Cable Rearrangement and Ferrite Absorber Addition

Fig. 11 shows the full spectrum of CE measurement by arranging the cable and adding a ferrite absorber. It points out four highest average values, denoted by the green diamonds. The highest average value of the measurement is 48.73 dBµV at 0.42 MHz.

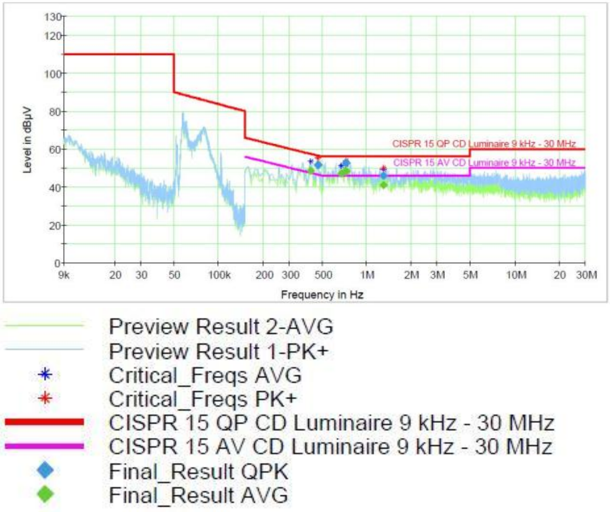

Figure 11. Full spectrum graph of CE Measurement with rearranged cable and the addition of a ferrite absorber.

From Table II, it appears that the average values after using the two simple techniques are reduced. The margin value is getting smaller after each treatment. Although after the two treatments, the average value is still above the limit set by the standard.

TABLE II. COMPARISON OF THE HIGHEST AVERAGE VALUE OF CE MEASUREMENT IN SMART STREET LIGHTING

EUT	Frequency (MHz)	Average (dBµV)	Limit (dBµV)	Margin (dB)
Basic measurement	0.43	49.98	47.22	-2.76
With rearranged cable	0.42	48.88	47.51	-1.37
With rearranged cable and addition of a ferrite absorber	0.42	48.73	47.50	-1.23

V. CONCLUSION

The conducted emission measurement of smart street lighting showed that the product still not complies with CISPR 15 standard. This happens because the manufacturer is not aware of the product requirement related to the EMC standard [26]. The proposed simple techniques can reduce the level of conducted emission. The reduction level due to the cable arrangement is higher than the ferrite absorber utilization. The use of ferrite absorber can still be optimized by investigating its placement in the EUT.

ACKNOWLEDGEMENT

The authors thank Electronic and EMC Laboratory, Center for Material and Technical Product, Ministry of Industry of the Republic of Indonesia.

REFERENCES

[1] Lighting Council Australia, "Discussion Paper Smart street lighting in Australia," no. July, pp. 1–17, 2016.
[2] E. Woods, "WHITE PAPER smart street lighting as a smart city platform applications and connectivity best practices," 2017.
[3] M. Mahoor, F. R. Salmasi, and T. A. Najafabadi, "A hierarchical smart street lighting system with brute-force energy optimization," *IEEE Sens. J.*, vol. 17, no. 9, pp. 2871–2879, 2017.
[4] R. Redl, "Electromagnetic environmental impact of power electronics equipment," *Proc. IEEE*, vol. 89, no. 6, pp. 926–938, 2001.
[5] F. Semiconductor, "EMI EMC considerations for energy," 2014.
[6] B. Keiser, *Principles of Electromagnetic Compatibility*, 3rd ed. Washington DC: Artech House, Inc, 1987.
[7] C. R. Paul, *Introduction to Electromagnetic Compatibility Second Edition*. 2006.
[8] H. W. Ott, *Electromagnetic Compatibility Engineering*. New Jersey: John Wiley & Sons, Inc, 2009.
[9] E. Kurniawan, D. Hamdani, S. Novario, D. Darwanto, and N. I. Sinisuka, "Mitigating Spikes for {EMC} in Vibration Monitoring Systems of Generating Plant," *Procedia Technol.*, vol. 11, no. 0, pp. 1127–1134, 2013.
[10] CISPR 15, *INTERNATIONAL STANDARD INTERNATIONALE*. 2013.
[11] J. Zhang, K. Qiu, L. Yin, R. Brooks, and B. Chen, "Ferrite bead model extraction and its application in high-performance ASIC analog power filtering," pp. 536–541, 2011.
[12] T. Miyashita, S. Nitta, and A. Mutoh, "Prediction of noise reduction effect of ferrite beads on electromagnetic emission from a digit a," pp. 866–871, 1998.
[13] T. H. Hubing and J. F. Kaufman, "Modeling the electromagnetic radiation from electrically small table-top products," *IEEE Trans. Electromagn. Compat.*, vol. 31, no. 1, pp. 74–84, 1989.
[14] T. H. Hubing, "Bundled cable parameters and their impact on EMI measurement repeatability.pdf." in *Proc. IEEE Symposium on EMC*, pp. 576–580, 1990.
[15] K. Wiles, "Shielding effectiveness of 'pigtail' connections," *1987 IEEE Int. Symp. Electromagn. Compat.*, pp. 253–259, 1987.
[16] C. E. Brench, "Effects of cable and peripheral placement," pp. 351–356, 1989.
[17] C. 16-1-1, *Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods – Part 1-1: Radio Disturbance and immunity Measuring Apparatus – Measuring Apparatus*. 2010, p. 166.
[18] C. 16-1-2, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Ancillary equipment – Conducted disturbances*. 2006, p. 162.
[19] C. 16-2-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements*. 2008, p. 152.
[20] J. Siira, "Emission test solution development for tablet computers," p. 77, 2015.
[21] Badan Standarisasi Nasional, "Persyaratan umum kompetensi Laboratorium Pengujian dan Laboratorium Kalibrasi (SNI ISO/IEC 17025:2008)," 2008.
[22] M. Mardiguian, "Overview of the civilian and military EMC norms." [Online]. Available: https://www.electronic.nu/2015/10/05/general-overview-of-the-civilianand- military-EMC-norms/. [Accessed: 20-Jan-2018].
[23] CISPR 13, *Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement*. 2009, p. 86.
[24] Z. Li, D. Pommerenke, and Y. Shimoshio, "Common-mode and differential-mode analysis of common-mode chokes," *2003 IEEE Symp. Electromagn. Compat. Symp. Rec. (Cat. No.03CH37446)*, vol. 1, no. September 2003, pp. 384–387, 2016.
[25] A. Racasan, C. Munteanu, V. Topa, C. Pacurar, C. Hebedean, and C. Marcu, "Home appliances conducted electromagnetic emissions analysis and mitigation methods," *2015 9th Int. Symp. Adv. Top. Electr. Eng. ATEE 2015*, pp. 356–361, 2015.
[26] D. Hamdani, I. Inayaturohman, and D. Darwanto, "State-of-the-art EMC regulation and conformity of products in Indonesia," *Proc. 2011 Int. Conf. Electr. Eng. Informatics, ICEEI 2011*, no. July, pp. 0–3, 2011.

Hardiles was born in Indonesia 1 December 1982 received Bachelor degree in Electrical Engineering from Gadjah Mada University, Yogyakarta, Indonesia in 2007 and Master degree of Electrical Engineering in Bandung Institute of Technology, Bandung, Indonesia in 2018.
Currently, he is an accreditation officer at National Accreditation Committee of Indonesia and also the National Standardization Agency of Indonesia. His primary research interest includes electromagnetic compatibility, renewable energy.

Wisnu Ananda was born in Indonesia 1 August 1983 received Bachelor degree in Electrical Engineering from Gadjah Mada University, Yogyakarta, Indonesia in 2008 and Master Degree on School of Electrical and Electronics Engineering in The University of Manchester, the UK in 2016. Since 2018 he is taking PhD programme in the Faculty of Physics, University of Vienna, Austria.
Currently, he is a researcher and testing engineer at Balai Besar Bahan dan Barang Teknik (B4T), Ministry of Industry, Indonesia. His primary research interest includes electromagnetic compatibility and solar cell technologies.

Seto Ayom Cahyadi was born in Indonesia 11 September 1990 received Bachelor degree in Electrical Engineering from Diponegoro University, Semarang, Indonesia in 2013.
Currently, he is Testing Engineer at Balai Besar Bahan dan Barang Teknik (B4T), Ministry of Industry, Indonesia. His main research interest includes electromagnetic compatibility, solar cell, and photovoltaic.

Tri Desmana Rachmildha received the B.Eng, M.Eng and Dr. degrees in Electrical Engineering from Bandung Institute of Technology, Indonesia, in 1998, 2002, and 2009, respectively. Currently, he is a lecturer at the School of Electrical Engineering and Informatics, Institut Teknologi Bandung. His main research interest includes power electronic, renewable energy.

Deny Hamdani received the B.Eng, M.Sc and Dr.-Ing degrees in Electrical Engineering from Bandung Institute of Technology, Indonesia, Karlsruher Institut fur Technologie and Technische Universitaet Dortmund, Germany in 1997, 2003, and 2012, respectively. He was research fellow at Nagoya University Japan, RWTH Aachen University Germany and Kyushu Institute of Technology Japan. Currently, he is a lecturer at the School of Electrical Engineering and Informatics, Institut Teknologi Bandung. His primary research interest includes electromagnetic compatibility, power quality, smart grid, renewable energy.