Study of harmonic distortion from variable speed drive and energy saving lamps

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Article Info	ABSTRACT
	The power electronic component has been widely used in the current industrial era. It has been considered more efficient than the previous devices as it saves more space and uses less power. One example of power electronic components is the variable speed drive for speed regulation of electric motors in the industrial world. Another application of power electronic components is to be used in energy-saving lamps. The use of power electronic components in these two loads generates harmonic distortion and reduces network power quality. In this paper, the authors analyzed the harmonics in both loads. As a result, the total harmonic distortion (THD) current for four energy-saving lamps is 88.3%. Meanwhile, the THD current at the 50 Hz, 5 A, and variable speed drive is 46.2%. After mixing the two loads, the THD current decreases by around 35%. *This is an open access article under the [CC BY-SA](#) license.* ![CC BY-SA]

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1. INTRODUCTION

The widespread use of computers, televisions and electrical loads based on the switching process has caused harmonic distortion in the distribution network. Increased damaged harmonic distortions can cause several disturbances and damages, such as overheating transformers, overheating conductor wires, damage to capacitor banks, disruption of communication systems, and electrical equipment malfunction [1]. The losses caused by network impedance will also be more significant if there is harmonic distortion. It will cause damage to parallel loads and unbalance the system. Due to this, there is increasing interest in improving the grid's electrical power quality caused by harmonic distortion in the electricity industry. Apart from worsening the quality of electric power, harmonic distortion also increases the cost of using the customer's load.

In the last ten years, power electronic components have been widely used in the industrial era. Its use is considered more efficient in terms of power consumption, and its construction saves space. One of the benefits of power electronics components is the variable speed drive for electric motors' speed regulation. Variable speed drive was applied to industries that use pumps, conveyors, fans, compressors, water mixers, and others to get various speeds. The variable speed drive is more efficient in power consumption than the previous method, which used the variable resistor. However, the variable speed drive has a disadvantage, such as producing harmonic disturbances caused by the power electronic components. If this is allowed, it will worsen the quality of the power grid system. Furthermore, on the lighting side, the use of power electronics is found in energy-saving lamps. Energy-saving lamps have begun to be widely used to replace incandescent lamps. This lamp is more power-efficient, and the resulting lumen is greater than incandescent

lamps. However, due to electronic ballasts containing electronic components, these lamps will cause harmonic disturbances. As with the variable speed drive, this will result in low electrical power quality on the network. In the research conducted by Kaendler [1], the difference in phase angle on the harmonics causes a change in the harmonics' magnitude.

Furthermore, in Hansen *et al.* [2], the harmonics' magnitude was reduced when 3-phase and 1-phase non-linear loads were combined. This happens because the harmonic phase angles of the two loads cancel each other out, and it reduces the harmonics. This condition can calculate by adding the harmonics' two magnitudes in a vector, not arithmetic. Thus, the authors are interested in analyzing the harmonics that arise in the variable speed drive and energy saving lamps and seeing the harmonic changes when the two loads are combined simultaneously. Research on the harmonics of these two loads has never been done before [3].

2. THEORETICAL BACKGROUND
2.1. Harmonic index

Harmonics are disturbances in electric power distribution caused by the distortion of current and voltage waves. Following the word distortion (change/deviation), harmonics cause a change in current and voltage waveform from an originally perfectly sinusoidal wave to a non-sinusoidal wave. The harmonic index has several indicators, such as individual harmonic distortion (IHD) and total harmonic distortion (THD). According to the Institute of electrical and electronics engineers (IEEE), individual harmonic distortion (IHD) is the ratio between the root mean square (RMS) value of each harmonic current and the fundamental current RMS value of the first harmonic. Based on this index, the first harmonic or fundamental current is always 100% [4], [5]. IHD applies to current (IHDI) and voltage (IHDv).

Total harmonic distortion (THD) is the ratio between all harmonic components' RMS value and the fundamentals' RMS value, usually expressed in percent (%). THD is also often called a distortion factor (distortion factor). The THD value measures the amount of deviation from the periodic waveform containing harmonics to the pure sinusoidal wave. The THD value is 0% [6]-[8]. The wave does not experience any deviation from the fundamental wave. The greater the THD value, the greater the resulting deviation, and the more damaging the network power quality. Therefore, given the maximum standard value of THD as a tolerable limit to not damage the network's quality. THD applies to current (THDi) and voltage (THDv). THDi and THDv value as described in (3) and (4).

The current distortion (THDi) at each load can vary. The value can range from a few percent to more than 100%. However, the voltage distortion (THDv) is generally less than 5%. THD voltages below 5% are not considered a nuisance. However, if the value is greater than 10%, it is already a disturbance and will cause sensitive electrical equipment. Besides THD, another index is used to determine standard harmonics, namely total demand distortion (TDD). TDD is the ratio of the total RMS value of harmonic currents to the network's maximum current load [8]. The calculation of the TDD value is described in (5). Harmonics also results in a low power factor, as shown in (6), the relationship between the power factor and THD. As shown in (6) is that the power factor will be lower if the THD of the current is greater [9], [10]. To calculate the harmonic distortion [4]-[6].

$$IHD_I = \frac{I_k}{I_1} \times 100\% \tag{1}$$

$$VHD_V = \frac{V_k}{V_1} \times 100\% \tag{2}$$

$$THD_I = \frac{\sqrt{\sum_{n=2}^{\infty} I_k^2}}{I_1} \tag{3}$$

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_k^2}}{V_1} \tag{4}$$

$$TDD = \frac{\sqrt{\sum_{n=2}^{\infty} I_k^2}}{I_L} \tag{5}$$

$$Pf = \frac{\cos \varphi}{\sqrt{1+THD^2}} \tag{6}$$

In this equations: I_k : RMS value of the harmonic current, I_1 : Fundamental current RMS value, V_k : RMS value of harmonic voltage, V_1 : Fundamental voltage RMS value, *Pf* : Power factor.

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2.2. Variabel speed drive

Variable speed drive (VSD)/variable frequency drive (VFD)/Inverter is a device used to control an electric motor's speed by controlling the voltage and frequency to be supplied to the motor [7], [8]. Setting the frequency and voltage values is intended to obtain the desired rotation speed and motor torque [12]-[15] as described in (7).

$$N_s = \frac{120F}{P} \tag{7}$$

In these equations: N_s : Stator rotation speed (RPM), F : Frequency (Hz), P : Number of poles (Pole).

In simple terms, an inverter's basic principle is that it can change the frequency to be smaller or bigger by changing the ac voltage into dc voltage and then changing it again into ac voltage with the desired frequency. To convert ac to dc voltage requires a rectifier (ac-dc converter) and usually uses an uncontrolled rectifier (rectifier-diode). After the ac voltage is converted to dc, it is necessary to improve the dc voltage's quality by using a capacitor reservoir as the voltage leveler of the ripple that appears [16]-[19]. The dc voltage is then converted into ac voltage again with an inverter using the pulse width modulation (PWM) technique. The output amplitude and frequency will be obtained as desired with the PWM technique. This technique will produce an alternating current (AC) wave that is sinusoidal in shape. Changing the dc to ac voltage usually uses semiconductor components from the transistor family, such as metal oxide semiconductor field efect transistor (MOSFETs), and insulated-gate bipolar transistor (IGBTs). This process causes the harmonics to be analyzed by the writer later, as shown in Figure 1.
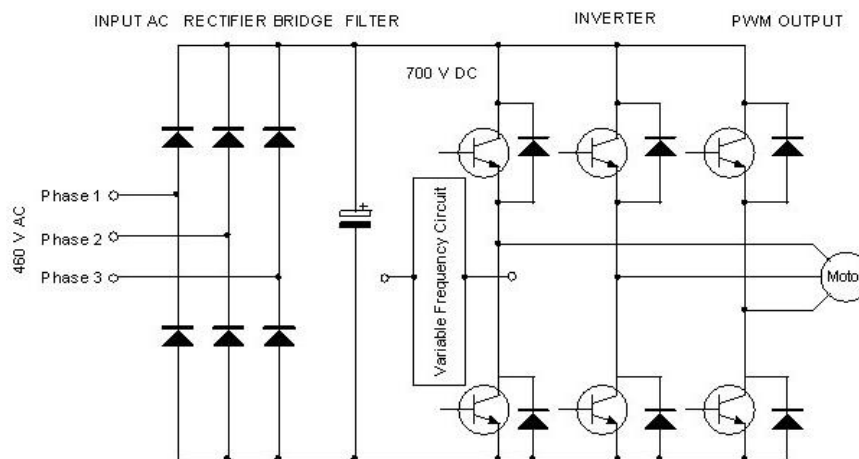

Figure 1. Series on a variable speed drive

2.2. Energy saving lamp

One of the non-linear loads that produce harmonics is energy-saving lamps. Energy-saving lamps have the same working principle as fluorescent lamps, namely, smearing the gas in the tube with a current, causing a light beam. A high-frequency voltage is needed to ionize the gas in the tube around 20 kHz-60 Khz [20]-[22]. Therefore, an electronic converter (ballast) is required as an ac to dc voltage converter, converting it back into ac voltage with high frequency.

Electronic ballasts contain semiconductor components that can cause harmonics in the network. The change in voltage from ac to dc then becomes ac again, causing wave distortion so that the waveform is not sinusoidal. Figure 2 shows the electronic ballast circuit. Block one filters and limits the peak current that enters the component. Block 2 is a bridge rectifier circuit that converts ac voltage to dc. Block 3 is a capacitor that reduces ripple and temporary storage of dc voltage. Furthermore, Block 4 is an inverter circuit that converts dc voltage into ac voltage with high frequency [23]-[25].
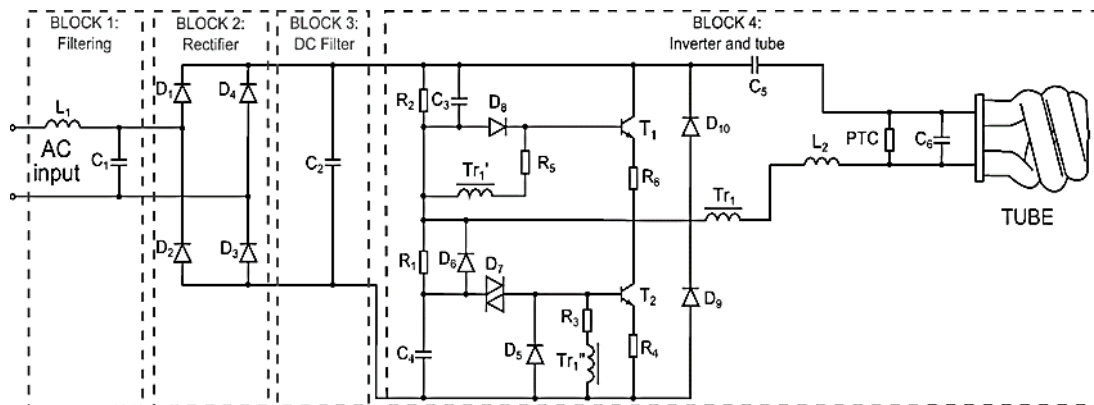
Figure 2. Electronic ballast circuit

3. RESEARCH METHOD

The variables to be observed in this study are as shown in: i) Total harmonic distorsion current (THDi). ii) Magnitude and phase angle of harmonic currents in the order (IHDi). iii) Harmonic current spectrum of order. iv) Current, voltage, and power generated by the load. All of the above variables have been observed for each non-linear load, namely the variable speed drive and energy saving lamps. The results were compared with mixing a load of variable speed drive and energy saving lamp, whether it did change. Changes to these variables have taken effect based on the speed and torque settings in the variable speed drive and the addition of the energy saving lamp load, which has been carried out gradually. The block diagram of the harmonic measurement circuit is seen in Figure 3.
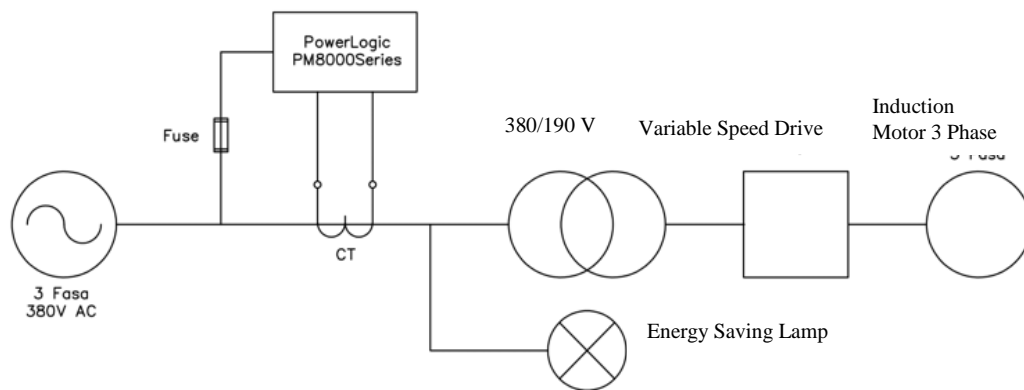
Figure 3. Harmonics measurement circuit

3.1. Harmonics measurement on variable speed drive and energy saving lamps.

The harmonic measurement of variable speed drive and energy saving-lamp, as shown in Figure 4. In Figure 4(a), the results of our experiment record the THD data of harmonic currents, magnitude, the phase angle of harmonic currents, current harmonic spectrum, current, voltage, and load power. Meanwhile, in Figure 4(b), the addition of saving lamps is done gradually to see the relationship between the increase in load current and the amount of harmonic current that occurs. Measurements are carried out with the load conditions of each phase being balanced (symmetrical).
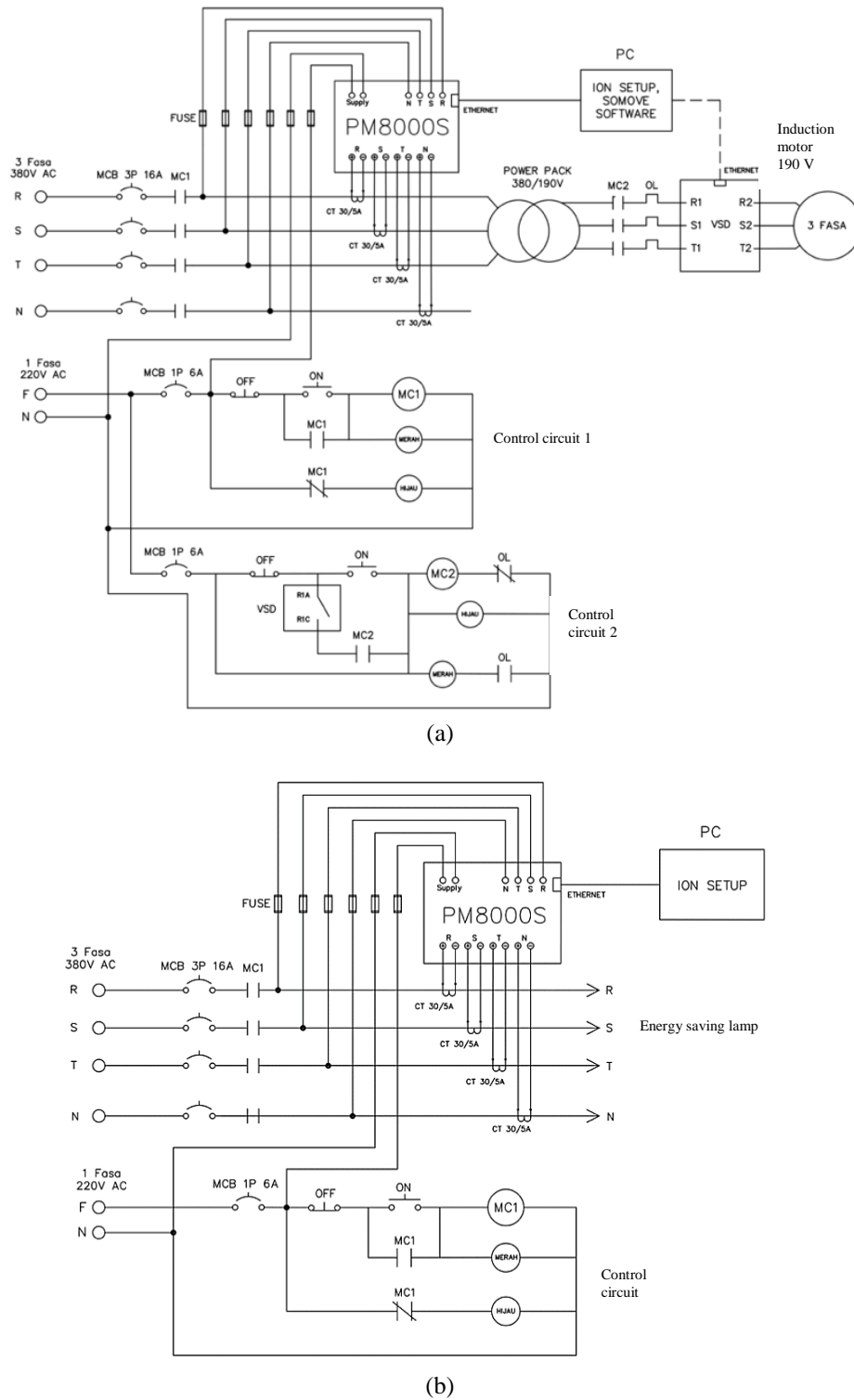
(a)

(b)

Figure 4. Harmonics measurement series on (a) variable speed drive and (b) energy saving-lamps

3.2. Harmonics measurement on mixed loads of variable speed drive and energy saving lamps

Figure 5 shows the harmonics measurement on mixed loads of variable speed drive and energy-saving lamps. Changes in speed variations on the variable speed drive and the addition of torque on the motor can be adjusted and accompanied by an increase in the number of energy saving lamps. After that, the changes in harmonics will be analyzed against changes in conditions in the mixed load between variable speed drive and energy saving lamps.
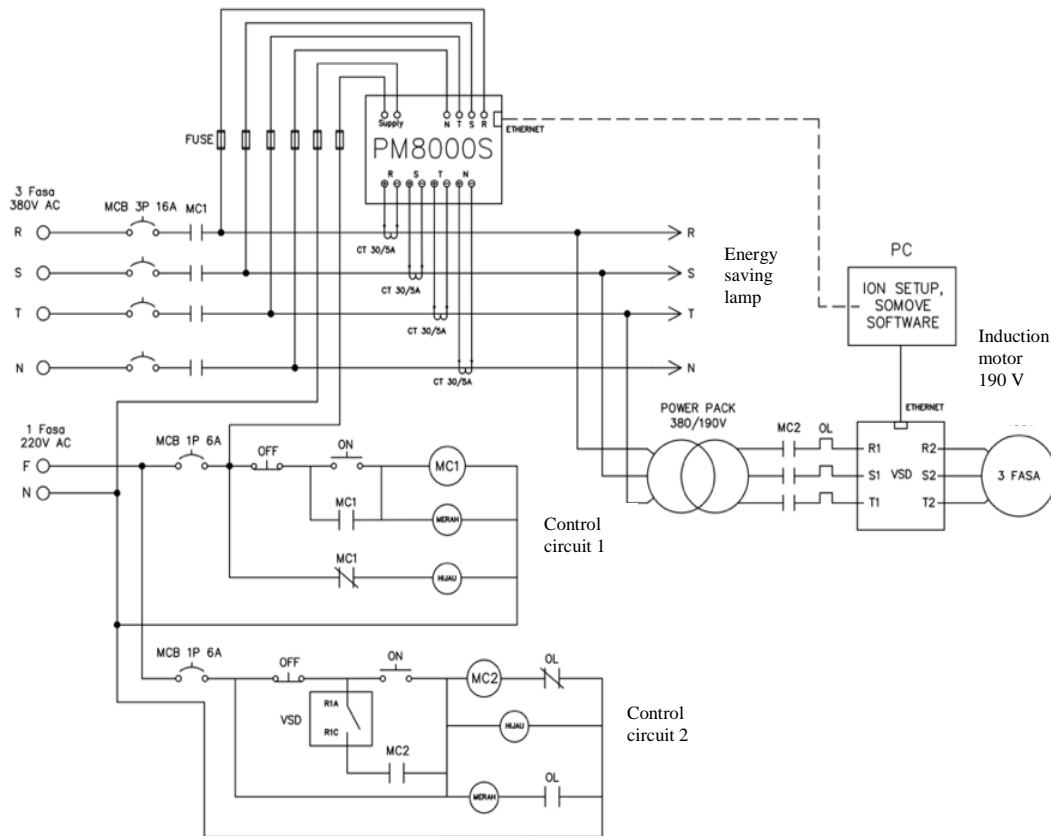
Figure 5. Harmonics measurement series on variable speed drive and energy saving lamps

4. RESULTS AND ANALYSIS
4.1. Harmonics measurement results on variable speed drive

Figure 6 Shows the variable speed drive's current increase by odd harmonics and dominated by the 5th and 7th order harmonics. In the 25 Hz condition, the higher current THD was obtained compared to the 50 Hz condition, both at different load conditions. In the 25 Hz, 4A conditions, the THD value was 79.8%, while at the 50 Hz, 4A conditions, the THD value was 51.3%. The difference between the two conditions is quite large. It can happen because the switching that occurs in the MOSFET is more common in conditions of 25 Hz than 50 Hz. In the 25 Hz condition, the 4A MOSFET did more switching because it had to change the 220 V input voltage to 95 V with a frequency of 25 Hz.

Meanwhile, in the 50 Hz condition, the 4A MOSFET will do less switching because it only changes the voltage to 175 Hz with 50 Hz. Therefore, the more switching that occurs, the greater the harmonics. However, when there is an increase in load current at constant frequency conditions, there is a decrease in harmonic distortion. For example, the THD value of the current at 50 Hz (4 A) is 51.3%. Meanwhile, the current THD value in 6 A is 37.5%. The load current increases, making the fundamental current also increases. As shown in Figure 6, the harmonic magnitude in the 5th order increases when the load current has an addition. However, the magnitude of the harmonics in the 7th order has decreased due to the different harmonic angles at the two loads. This difference causes the vector addition of the two harmonic magnitudes has reduced. On the other hand, the magnitude of the harmonics in the 5th order tends to increase due to the relatively equal magnitude of the harmonics' phase angle. The magnitude of the harmonics increases.

4.2. Harmonics measurement results on energ saving lamps

According to the harmonic spectrum shown in Figure 7. the increase in load current is caused by odd-order harmonics, which are dominated by 3rd, 5th, 7th, 11th, and 13th order harmonics as the five order harmonics with the highest value. The value of each harmonic order is affected by how many lamps are turned on. Increasing the value of each harmonic order will also affect the amount of THD of the lamp's current. For example, when two lights are on, the THD value of the current that arises is 82.3%. However, when ten lamps are on, the THD value of the current increases to 109%. There was an increase of 26.7%. When viewed carefully, the increase in current THD under increasing load conditions is because the current

harmonics in the 5th, 7th, 11th, and 13th orders increase significantly. The 5th order harmonics are 26.4% in the condition of two lights on. Further, the ten lights have turned, and the 5th order harmonics are 52%. There was an increase of 25%. This also occurred in the 7th, 11th, and 13th orders, where the increase was around 30-50%. However, the harmonics in the 3rd order have decreased. This is inversely proportional to the previous condition. These things can happen because the increase in the 3rd order magnitude increase is not as drastic as the 5th, 7th, 11th, and 13th harmonics. When the magnitude of the 3rd order is converted into a spectrum form, it seems as if it has decreased because the increase in the divider (fundamental current) is more drastic than the harmonic order's value.
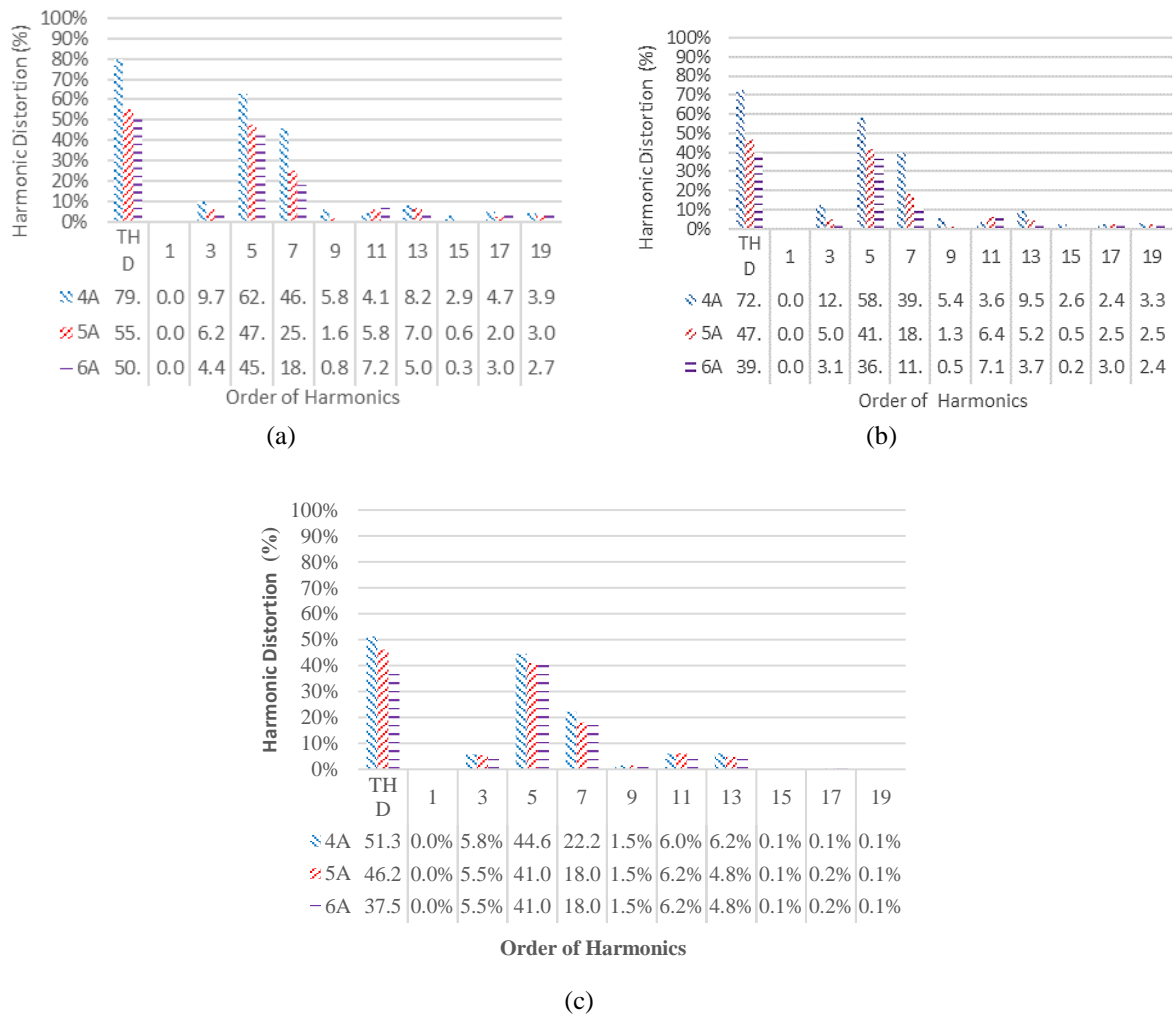

(a)

(b)

(c)

Figure 6. Harmonic distortion of variable speed drive at (a) 25 Hz, (b) 37.5 Hz, and (c) 50 Hz

4.3. Harmonics measurement results on mixed loads of variable speed drive and energy saving lamps

Figure 8 shows the harmonics spectrum on variable speed drive Figures 8(a) 25 Hz, 8(b) 37.5 Hz, and 8(c) 50 Hz, 5 A, and energy saving lamps. The increase in load current caused odd-order harmonic distortion dominated by 3rd, 5th, 7th, 11th, and 13th orders in each condition whose magnitude is above 20%. The magnitude of each harmonic order affected the THD value of harmonic currents. Meanwhile, the increase in the number of energy saving lamps that are turned on periodically and the addition of speed and current to the variable speed drive causes the THD of the harmonic current to decrease. The decrease in the THD value of Harmonia current occurs slowly following the addition of both loads and increasing the variable speed drive speed.
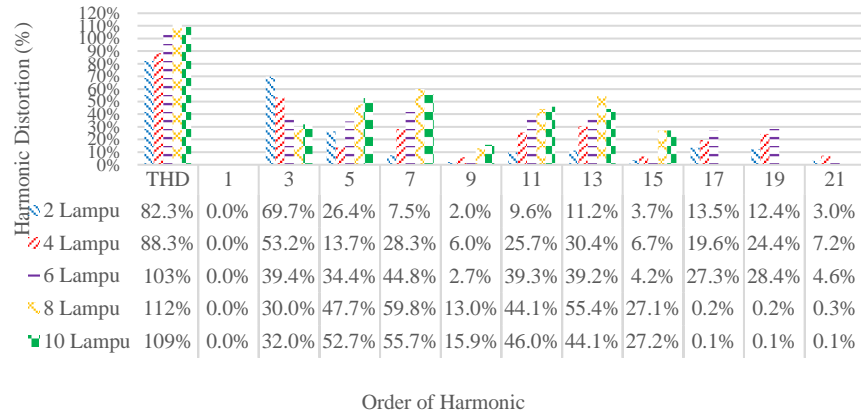
Order of Harmonic	THD	1	3	5	7	9	11	13	15	17	19	21
2 Lampu	82.3%	0.0%	69.7%	26.4%	7.5%	2.0%	9.6%	11.2%	3.7%	13.5%	12.4%	3.0%
4 Lampu	88.3%	0.0%	53.2%	13.7%	28.3%	6.0%	25.7%	30.4%	6.7%	19.6%	24.4%	7.2%
6 Lampu	103%	0.0%	39.4%	34.4%	44.8%	2.7%	39.3%	39.2%	4.2%	27.3%	28.4%	4.6%
8 Lampu	112%	0.0%	30.0%	47.7%	59.8%	13.0%	44.1%	55.4%	27.1%	0.2%	0.2%	0.3%
10 Lampu	109%	0.0%	32.0%	52.7%	55.7%	15.9%	46.0%	44.1%	27.2%	0.1%	0.1%	0.1%

Figure 7. Harmonic spectrum of energy saving lamp

Order of Harmonic	THD	1	3	5	7	9	11	13	15	17	19	21
2 Lampu	52.	0	26.	38.	16.	1.4	7.6	6.7	1.3	3.7	6.5	0.5
4 Lampu	49.	0	29.	18.	1.4	2.2	17.	14.	1.9	12.	13.	1.6
6 Lampu	56.	0	13.	13.	18.	3.1	19.	15.	1.9	13.	9.4	0.2
8 Lampu	67.	0	16.	15.	24.	1.5	23.	20.	1.8	15.	11.	1.5
10 Lampu	74.	0	12.	21.	28.	1.4	27.	20.	0.6	16.	10.	1.1

(a)

Orde Harmonisa	THD	1	3	5	7	9	11	13	15	17	19	21
2 Lampu	44.	0.0	21.	34.	11.	1.3	7.5	3.8	1.4	2.7	4.7	0.9
4 Lampu	43.	0.0	25.	18.	3.7	1.7	16.	11.	1.4	11.	10.	0.6
6 Lampu	53.	0.0	19.	14.	18.	3.7	25.	19.	2.4	17.	13.	0.5
8 Lampu	63.	0.0	21.	20.	27.	2.0	29.	24.	2.4	18.	16.	2.3
10 Lampu	69.	0.0	14.	25.	31.	1.6	30.	23.	0.8	17.	12.	0.8

(b)

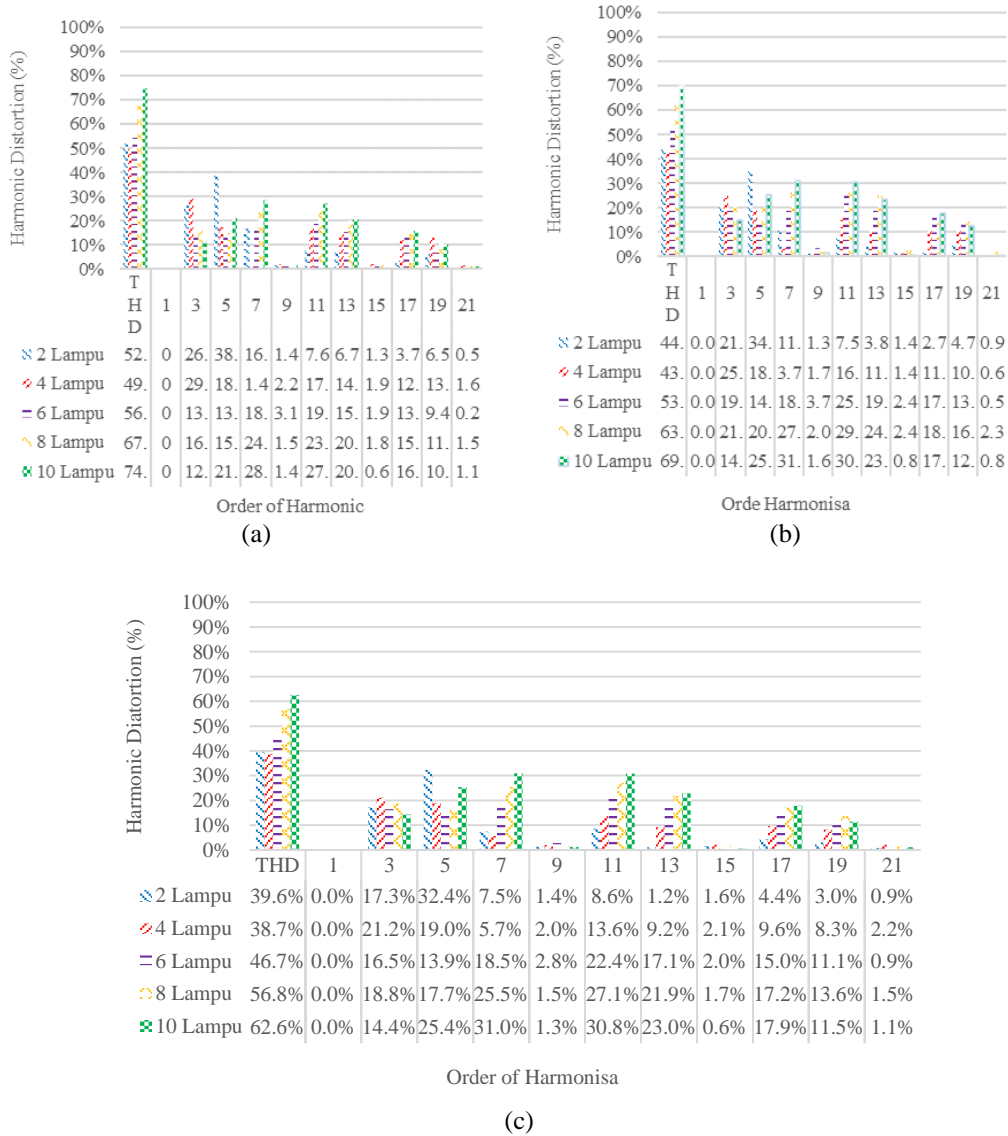| Order of Harmonisa	THD	1	3	5	7	9	11	13	15	17	19	21
2 Lampu	39.6%	0.0%	17.3%	32.4%	7.5%	1.4%	8.6%	1.2%	1.6%	4.4%	3.0%	0.9%
4 Lampu	38.7%	0.0%	21.2%	19.0%	5.7%	2.0%	13.6%	9.2%	2.1%	9.6%	8.3%	2.2%
6 Lampu	46.7%	0.0%	16.5%	13.9%	18.5%	2.8%	22.4%	17.1%	2.0%	15.0%	11.1%	0.9%
8 Lampu	56.8%	0.0%	18.8%	17.7%	25.5%	1.5%	27.1%	21.9%	1.7%	17.2%	13.6%	1.5%
10 Lampu	62.6%	0.0%	14.4%	25.4%	31.0%	1.3%	30.8%	23.0%	0.6%	17.9%	11.5%	1.1%

(c)

Figure 8. Harmonics spectrum on variable speed drive (a) 25 Hz, (b) 37.5 Hz, (c) 50 Hz, 5A and energy saving lamps

Figure 9 shows a large reduction in the THD magnitude of harmonic currents when mixing the two loads. The THD value of the current at the 50 Hz 5 A variable speed drive is 46.2%, and the energy saving lamp is as much as ten pieces of 88.3%. After the two mixed loads, the current THD decreased to 35.0%. There was a decrease in the current THD of 11.2% for variable speed drives and 53.3% for energy-saving lamps. It also happens in every harmonic order. The reduction in the value of harmonic distortion occurs at odd-order harmonics. The most drastic decline occurred in the 3rd, 5th, 7th, 11th, and 13th orders. In the 7th order, the harmonic distortion value at both loads decreased after mixing. The amount of harmonic distortion before mixing on the variable speed drive is 18%, while the energy saving lamp is 28.3%. After the two loads were mixed, the distortion value decreased to 7.0%. The decrease in harmonic distortion value in each order is due to the different magnitude of the harmonic order's phase angle on the two loads. The difference in the phase angle will cause the magnitude of the harmonic order on the two loads to cancel each other out. The resultant value of each harmonic order has been reduced, resulting in reduced harmonic distortion

	THD	1	3	5	7	9	11	13	15	17	19	21
VSD 50Hz 5A	46.2%	0.0%	5.5%	41.0%	18.0%	1.5%	6.2%	4.8%	0.3%	2.5%	2.4%	0.2%
4 LHE	88.3%	0.0%	53.2%	13.7%	28.3%	6.0%	25.7%	30.4%	6.7%	19.6%	24.4%	7.2%
VSD 50Hz 5A + 4 LHE	35.0%	0.0%	18.2%	19.2%	7.0%	1.9%	12.0%	7.9%	2.2%	8.5%	6.2%	2.2%

Order of Harmonic
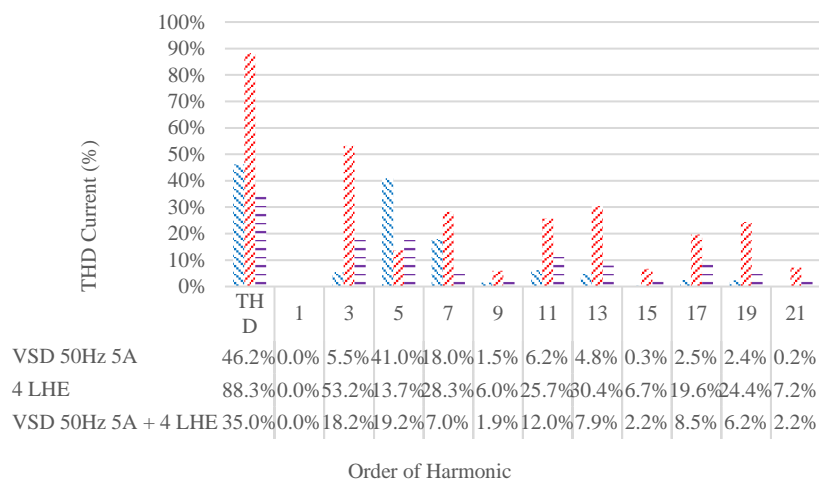
Figure 9. Comparison of THD flow before and after mixing loads

5. CONCLUSION

As the research results, mixing a load of variable speed drive and energy saving lamps in each condition decreases the current THD value. Following this result, fundamental harmonic current (1st order) is the basic current used by electric motors to move. However, harmonic distortion in the 2nd order to the 20th order causes the load current on the Variable Speed Drive, measured by metering, to increase. Furthermore, the THD value of the current generated by the 50 Hz 5 A variable speed drive is 46.2%, while the THD of the current in 4 energy saving lamps is 88.3%. The last conclusion, the lowest current THD value occurs in the mixing conditions of the variable speed drive 50 Hz 5 A with 4 energy saving lamps of 35.0%. There was a decrease in the current THD of 11.2% at the 50 Hz 5 A variable speed drive and 53.3% at 4 energy saving lamps.

REFERENCES

[1]   G. Kaendler, "Voltage Distortion in high voltage networks caused by switched mode power supplies," in *Power Quality Conference*, 1995, pp. 117–129.
[2]   S. Hansen, P. Nielsen, and F. Blaabjerg, "Harmonic cancellation by mixing nonlinear single-phase and three-phase loads," *IEEE Transactions on Industry Applications*, vol. 36, no. 1, pp. 152–159, 2000, doi: 10.1109/28.821810.
[3]   A. V. Khergade, R. J. Satputaley, V. B. Borghate, and B. V. S. Raghava, "Harmonics reduction of adjustable speed drive using transistor clamped h-bridge inverter based DVR with enhanced capacitor voltage balancing," *IEEE Transactions on Industry Applications*, vol. 56, no. 6, pp. 6744–6755, Nov. 2020, doi: 10.1109/TIA.2020.3013823.
[4]   S. M. Islam, M. J. Hamilton, W. B. Lawrance, and C. V. Nayar, "Investigation of harmonics from variable speed drives with six pulse rectifiers under imperfect supply conditions," in *Conference Record - IAS Annual Meeting (IEEE Industry Applications Society)*, 2000, vol. 3, pp. 1625–1631, doi: 10.1109/ias.2000.882099.
[5]   C. Brusil, H. Arcos, F. Espin, and C. Velasquez, "Analysis of harmonic distortion of led luminaires connected to utility grid," in *2020 Ieee Andescon, Andescon 2020*, Oct. 2020, pp. 1–6, doi: 10.1109/ANDESCON50619.2020.9272004.
[6]   C. Perdahci, "Harmonic analysis of LED biodynamic lighting luminaires in buildings," in *2019 International Symposium on Advanced Electrical and Communication Technologies, ISAECT 2019*, 2019, pp. 1–6, doi: 10.1109/ISAECT47714.2019.9069687.
[7]   H. Shabbir, M. Ur Rehman, S. A. Rehman, S. K. Sheikh, and N. Zaffar, "Assessment of harmonic pollution by LED lamps in power systems," in *2014 Clemson University Power Systems Conference, PSC 2014*, Mar. 2014, pp. 1–7, doi: 10.1109/PSC.2014.6808099.

[8]   P. Straczynski and M. W. Cislik, "Higher harmonics and power in circuits with LED light sources," in *Proceedings of the 2018 Conference on Electrotechnology: Processes, Models, Control and Computer Science, EPMCCS 2018*, Nov. 2018, pp. 1–5, doi: 10.1109/EPMCCS.2018.8596561.

[9]   R. C. Dugan, M. F. McGranaghan, S. Santoso, and H. W. Beaty, *Electric Power System Quality*, 3rd edition. USA: CRC Press LLC, 2004.

[10]   J. C. Montaño, M. D. Borrás, M. Castilla, A. López, J. Gutiérrez, and J. C. Bravo, "Harmonic distortion index for stationary and transient states," in *CPE 2009 - 6th International Conference-Workshop - Compatability and Power Electronics*, May 2009, pp. 123–128, doi: 10.1109/CPE.2009.5156023.

[11]   L. Zhong, "The harmonic index for graphs," *Applied Mathematics Letters*, vol. 25, no. 3, pp. 561–566, Mar. 2012, doi: 10.1016/j.aml.2011.09.059.

[12]   H. A. Brantsæter, "Resonance Mode analysis and application for offshore wind power plants," Master thesis of Energy and Environmental Engineering, Norwegian University of Science and Technology, 2015.

[13]   C. Dzienis, A. Bachry, and Z. Styczynski, "Full harmonic load flow calculation in power systems for sensitivity investigation," in 17*th International Zurich Symposium on Electromagnetic Compatibility, 2006*, 2006, vol. 2006, pp. 646–649, doi: 10.1109/emczur.2006.215017.

[14]   A. K. Tagore and A. R. Gupta, "Harmonic load flow analysis of radial distribution system in presence of distributed generation," in *International Conference on Power and Embedded Drive Control, ICPEDC 2017*, Mar. 2017, pp. 147–151, doi: 10.1109/ICPEDC.2017.8081077.

[15]   L. Cristaldi and A. Ferrero, "Harmonic power flow analysis for the measurement of the electric power quality," *IEEE Transactions on Instrumentation and Measurement*, vol. 44, no. 3, pp. 683–685, Jun. 1995, doi: 10.1109/19.387308.

[16]   N. Bayan, "Harmonic flow analysis in power distribution networks," Master Thesis, University of Windsor, 1999.

[17]   R. K. Jujjuvarapu and B. Basavaraja, "Modelling and estimating voltage and current harmonics of variable speed drives (Vsd)," *International Journal of Power System Operation and Energy Management*, pp. 135–140, Apr. 2013, doi: 10.47893/ijpsoem.2013.1076.

[18]   M. Scheidiger, "Power system harmonics analysis of high power variable speed drives power system harmonics analysis of high power variable speed drives," Master's Thesis at Electric Energy Conversion Departmen. Stockholm, KTH Royal Institute of Technology, 2013.

[19]   S. Mohitkar and M. Dhend, "Harmonic measurement and analysis of variable frequency drive (vfd) in Industry," *International Journal of Research in Advent Technology*, vol. 2, no. 2, pp. 303–309, 2014.

[20]   A. Abraham, "Power quality analysis of variable speed drives. masters dissertation school of electrical and information engineering," Johannesburg. University of the Witwatersrand, 2014.

[21]   Taufik, E. Matsumoto, and M. Anwari, "Impact of multiple adjustable speed drive system to power system harmonics," in *PECon 2008 - 2008 IEEE 2nd International Power and Energy Conference*, Dec. 2008, pp. 324–328, doi: 10.1109/PECON.2008.4762492.

[22]   L. Frater, "Light flicker and harmonic modelling of electrical lighting," PhD thesis, Christchurch, New Zealand. University of Canterbury, 2015.

[23]   S. Adhigunarto, E. Mulyana, and W. Surya, "The analysis of harmonics on LED lamps," *IOP Conference Series: Materials Science and Engineering*, vol. 384, no. 1, p. 012061, Jul. 2018, doi: 10.1088/1757-899X/384/1/012061.

[24]   A. E. G. Trujillo, "Harmonics influence on power and energy measurements," *International journal of physical sciences and engineering*, vol. 3, no. 1, pp. 32–41, Mar. 2019, doi: 10.29332/ijpse.v3n1.254.

[25]   A. J. Collin *et al.*, "Analysis of approaches for modeling the low frequency emission of LED lamps," *Energies*, vol. 13, no. 7, p. 1571, Mar. 2020, doi: 10.3390/en13071571.

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