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Disturbance Characteristics of Induction Cooker on a Grid-Connected Photovoltaic System in Frequency Range of 9-150 kHz

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Abstract— This study aims to investigate the disturbance's characteristics induced by the induction cooker of the On-Grid PV System that is installed in the MRPQ at the Faculty of Engineering Universitas Indonesia (FTUI). In addition, this research is also to find out the behavior of the induction cooker on a frequency range of 9-15kHz. The load was connected to Switching Mode Power Supply (SMPS) that connected to the utility grid. Furthermore, the utilization of inverter that used SMPS technology may generate disturbance mostly at high frequency from 9 kHz to 150 kHz. Disturbance generated by each tool from the equipment in the PV system and household appliances may also affect each other in its operation. However, research and standardization regarding the effect of induction cooker disturbances on the PV system for frequency ranges of 9-150 kHz are still limited. Therefore, this research focuses on observing behavior and the characteristics of a disturbance generated by the induction cooker. There are two induction cookers investigated, brand A and B. The results show that the induction cooker generates disturbance at a frequency of 9-150 kHz, and the increased power used at the load will also increase the disturbance value. Furthermore, brand A has a more significant average incremental gradient compared to brand B induction cookers of 260% or 17.05mV / W for brand A and 6.58mV / W for brand B.

Keywords: power quality, disturbance characteristics, induction cooker, on-grid photovoltaic, 9-150 kHz

1. Introduction

Recently, many researchers investigate the use of renewable energy sources (RES), including the PV system, to replace the existing fossil power generation for power production [1] [2] [3]. The increased utilization of RES in power generation is due to the reduction of the greenhouse gas effect and secure the sustainability of energy sources connected to the electrical grid [4]. Furthermore, environmentally friendly technology also paid huge attention to the customer side of the electricity user, including the residents. Nowadays, many modern household appliances that have a green concept also introduced and used worldwide. As a result, there is growth in the implementation of RES and green household appliances found widely in the modern house, especially that implement a smart home system [5]. Yet, this renewable energy source integration to the grid, including the PV system, produce some challenge to be solved [6].

In the PV system, there is equipment called an inverter. The inverter is one of the power electronic circuits that used to convert the energy generated by PV in direct current (DC) form into the electrical grid, including a house system that is using alternating current (AC) to supply its appliances equipment loads [7] [8].

Some researchers reported that the PV system that connected to an electrical grid was found, generating a disturbance in the frequency range of 9-150 kHz [9] [10]. It was discovered by measuring the power quality profile of load, such as incandescent lamps that connected to the grid-connected PV system [11]. Nowadays, household appliances are generally installed with components of non-linear loads and using Switch Mode Power Supply (SMPS), which is switching at a high frequency [12] [13]. That switching has a higher value than the inverter technology inside the PV system, in which the PV system generates distortion (harmonics) at the frequency range around 2kHz. However, the standardization that regulates this power quality phenomenon of distortion frequency range 9-150 kHz, which is called disturbance, is still limited. As a result, the attention to limit this distortion problem for improving the power quality of the electrical grid in the resident area is not well enough [14]. Thus,

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some effort is still needed to show this power quality phenomenon induced by the RES and SMPS for accurate mitigation to be implemented in the near future.

This study investigates the characteristics of disturbance and behavior of non-linear household appliances loads such as induction cookers that connected to the on-grid PV system. The scope of this study is focusing on the frequency range of 9-150 kHz.

2. Data Acquisition Method

The measurement of this study was performed using PicoScope. It is a type of oscilloscope that can be connected to a personal computer for its operation. In this study, the PicoScope probes were connected to the high pass filter, which connecting the electrical load, which is an induction cooker with the output of an inverter. A high pass filter is used to capture the data of disturbance characteristics induced by the induction cooker at frequency range 9-150 kHz. After the disturbance data is collected, then it is processed by MATLAB software to check its power quality profile. Furthermore, the data is analyzed to find the range of disturbance frequency from the induction cooker load and its dominant frequency disturbance. The schematic diagram and the measurement point of the study are shown in Figure 1.

Furthermore, the measurement was performed on a PV system that connected to the utility grid, which is called an on-grid PV system. The induction cooker was connected to this system. Two different brands of induction cooker, brand A and brand B, were measured one by one to find the characteristics of each disturbance profile.

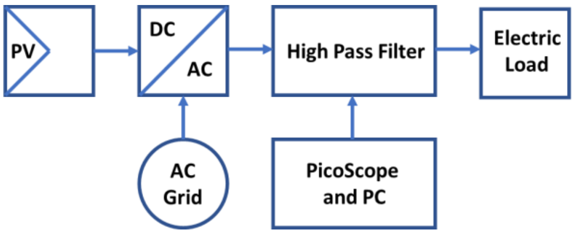

Figure 1. Measurement schematic

Table 1. PC Specification

PC Specification	ZenBook UX334FLC.303
Processor	Intel® Core i7-10510 CPU @ 1.8GHz
RAM	16 GB (DDR 4)
OS	Windows 10 Home 64-bit
Graphics Card	NVIDIA GeForce MX250

The specification of the PC used for data processing is explained in Table 1. And the detailed specification of the PicoScope 3000 series that used to capture the disturbance in the study is shown in Table 2. The data was processed and calculated using Fast Fourier Transformation (FFT) method in MATLAB. FFT is used to decompose the disturbance frequency signal within the system into its cosines and sines, as shown by eq (1) [15].

$$f(t) = x_o + \sum_{n=1}^{\infty}\left(x_n cos(2\pi nt) + y_n sin(2\pi nt)\right) \quad \text{(Eq.1)}$$

where,
x_o = DC offset value
x_n = Real component value on n frequency
y_n = Imaginary component value of n frequency
n = signal frequency

Table 2. Oscilloscope Specification

Oscilloscope	PicoScope 3000 Series
Max Voltage	400 Volts
Voltage type	AC/DC
Channel ports	4 Channels
Bandwidth	5 MHz
Resolution	12 Bit
Connectivity	USB 2.0
OS	Windows/Mac/Linux

3. Results and Discussion

The measurement of disturbance characteristic was conducted on two different brands of induction cookers. Both induction cookers were selected as they are commonly used by Indonesian domestic households.

3.1. Disturbance Characteristics of System without Electric Load

This measurement is aimed to look at the power quality profile of the on-grid PV system that having a power electronics device such as an inverter. The test is about finding the disturbance characteristics of the system without any induction cooker is connected. So, the difference of disturbance profile or characteristics can be compared between the system that has not been installed and the system that has been installed with an induction cooker.

The disturbance characteristics of the non-load PV system is shown in Figure 2. Although the system does not have any electric load attached, the measurement results show there are disturbances generated within the on-grid PV system. The disturbance found is dominantly at a frequency of 19.8 kHz with a value range between 596.14 to 713.34 mV.

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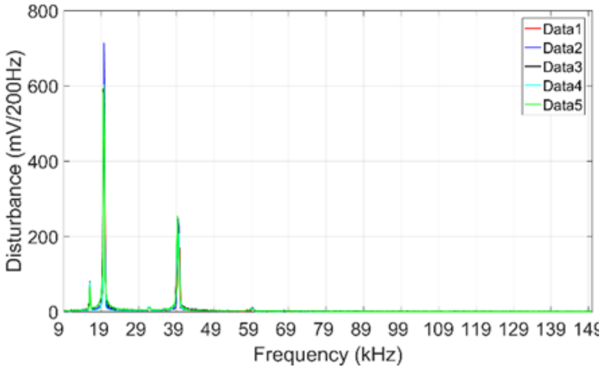

Figure 2. PV system Disturbance Characteristic w/o electric load

3.2. Disturbance Characteristics of Induction Cooker Brand A

The electric load used in this measurement were two brands of induction cooker, brand A and brand B. Each induction cooker has a different operation of power level. The specification of the power level that is written on the induction cooker can be seen on Table 3. This measurement is aimed to get the power quality profile, especially the disturbance characteristics of the induction cooker at frequency range 9-150 kHz.

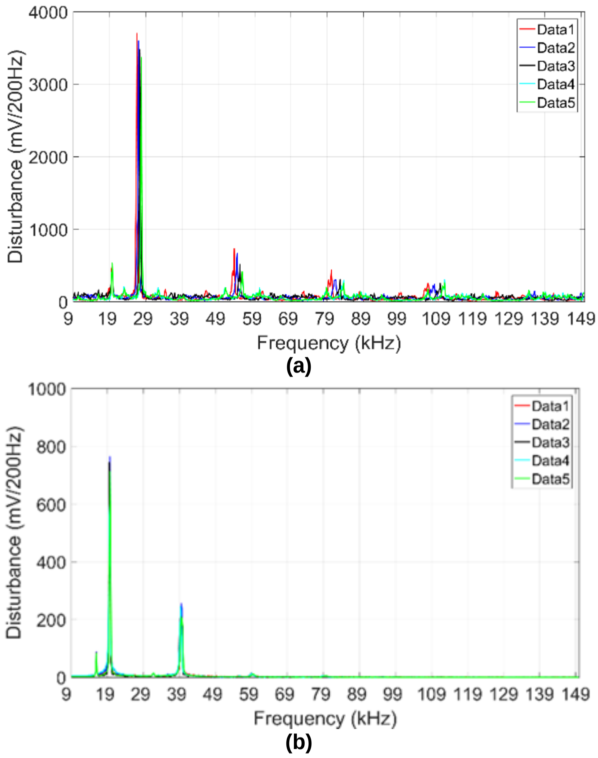

Figure 3. Disturbance profile of Brand A at 100W (a) upper cycle and (b) lower cycle

Table 3. Power level operation of electric load

No	Electric Load	Power Level (Watt)
1	Induction Cooker Brand A	100-200-300-400-500-550-600-800
2	Induction Cooker Brand B	100-400-1000-1400-1800-2100

The first measurement is conducted for the induction cooker brand A. It has eight levels of power level operation. All power level has a two-cycle operation called the upper cycle and bottom cycle. The upper cycle occurs when the induction cooker produces the heat by the induction process, whereas the bottom cycle is the state when the induction cooker is at rest period.

Disturbance characteristic of brand A induction cooker at level power operation of 100W is illustrated in Figure 3. As shown in that figure, the most dominant disturbance of the upper cycle is occurring at a frequency of 26.6 kHz with a value of 3669.091 mV. While the bottom cycle is at frequency 19.6 kHz with value 695.4384 mV. It can be seen from the 5 data sample; the most dominant disturbance of each cycle has a similar different gap size around 3000 mV. Additionally, the bottom cycle disturbance characteristic is a little bit higher han the no-load disturbance characteristic.

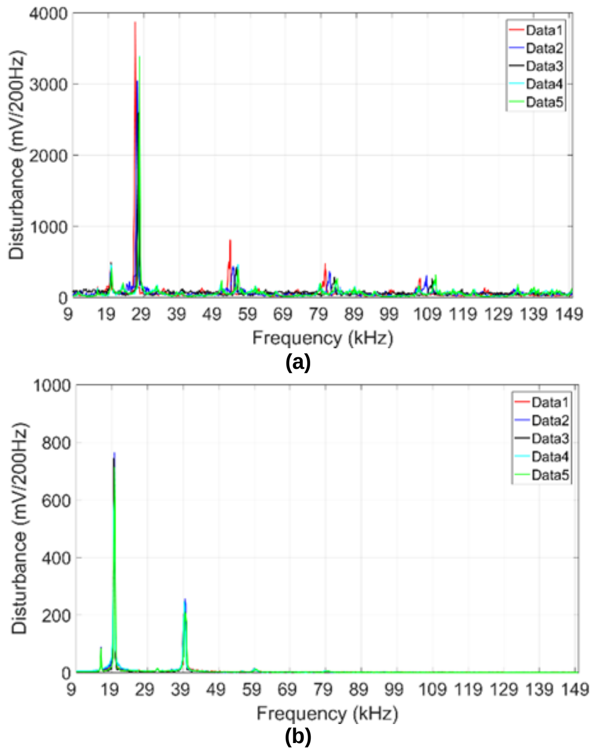

Figure 4. Disturbance profile of Brand A at 200W (a) upper cycle and (b) lower cycle

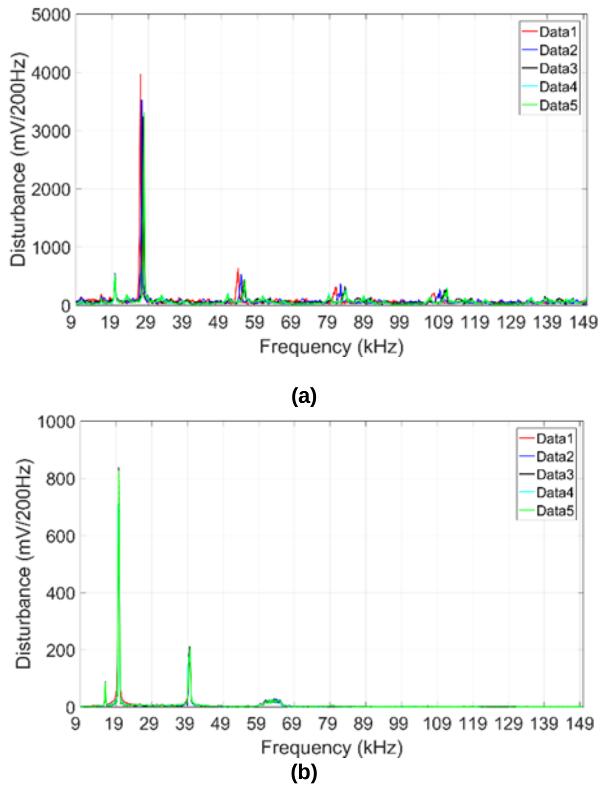

Figure 5. Disturbance profile of Brand A at 300W (a) upper cycle and (b) lower cycle

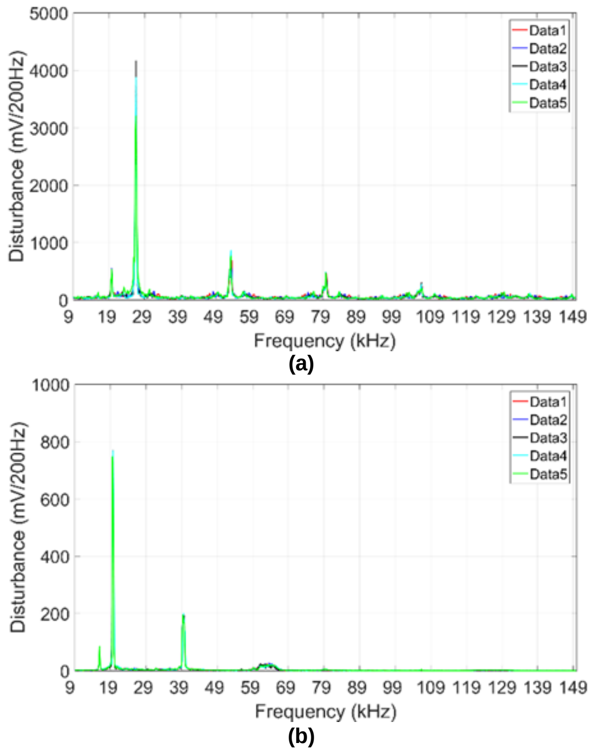

Figure 6. Disturbance profile of Brand A at 400W (a) upper cycle and (b) lower cycle

Figure 4 shows the disturbance profile of brand A at power level 200W. As shown in that figure, the most dominant disturbance of the upper cycle is at frequency 26.6 kHz, with a value of 3868.416 mV. While the bottom cycle is at frequency 19.8 kHz with value 763.3638 mV. It can be seen most dominant disturbance of each cycle has a different gap size of around 3000 mV.

Similarly, Figure 5 shows the power level 300W, the most dominant disturbance of the upper cycle is at frequency 26.8 kHz with value 3965.142 mV. While the bottom cycle is at frequency 19.8 kHz with value 836.656 mV. It can be seen most dominant disturbance of each cycle has a different gap size around 3100 mV.

Moreover, Figure 6 shows the power level 400W, the most dominant disturbance of the upper cycle is at frequency 26.6 kHz with value 4158.874 mV. While the bottom cycle is at frequency 19.8 kHz with value 768.7054 mV. It can be seen most dominant disturbance of each cycle has a different gap size around 3300 mV.

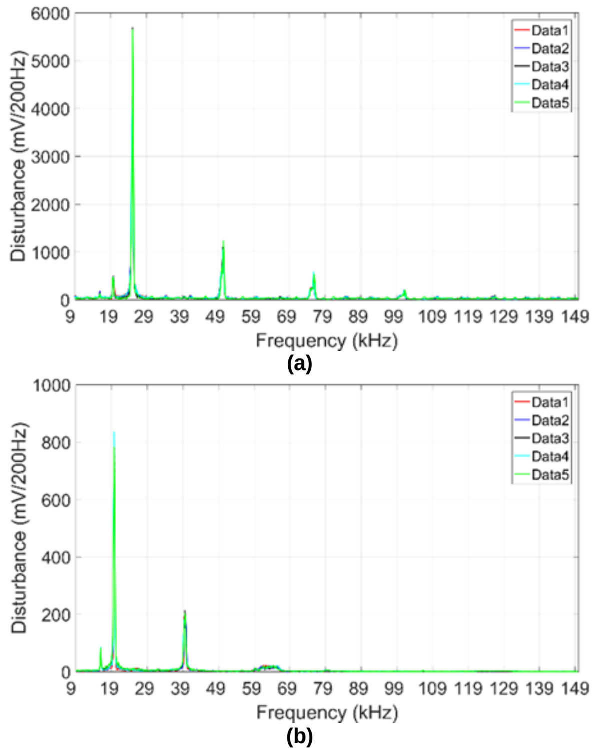

Figure 7. Disturbance profile of Brand A at 500W (a) upper cycle and (b) lower cycle

The disturbance profile for power level 500W is shown in Figure 7. the most dominant disturbance of the upper cycle is at frequency 25.2 kHz with value 5691.533 mV. While the bottom cycle is at

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frequency 19.8 kHz with value 834.0638 mV. It can be seen most dominant disturbance of each cycle has a different gap size around 4800 mV.

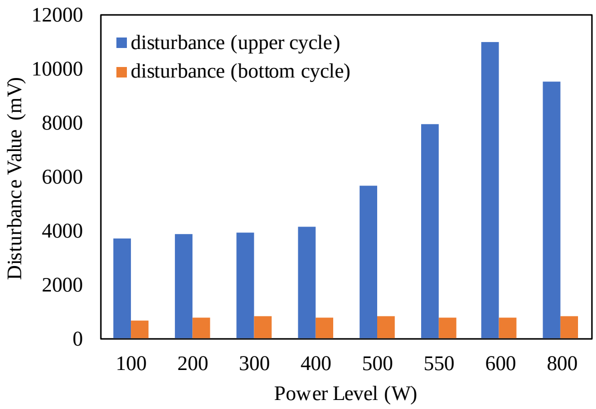

Table 4. Measurement Results 550 – 800 W

No	Power level (W)	Dominant frequency (kHz)	Disturbance value (mV)
1	550 Upper	24.2	7991.615
	550 Lower	19.8	782.301
2	600 Upper	22.2	11037.38
	600 Lower	19.8	802.9982
3	800 Upper	23.4	9536.965
	800 Lower	19.8	859.9632

Figure 8. Disturbance profile of Brand A for all operation power level for upper cycle

Furthermore, the process of data acquisition and measurement for the disturbance characteristic is taken for the operating power level of 550, 600, and 800 W. The results of the dominant disturbance are shown in Table 4.

Overall, the disturbance characteristic of brand A induction cooker for the test, which is taken from 5 data points for each power operation level are shown in Figure 8. The disturbance value is varied within a range of 3700 – 11038 mV. As illustrated in that figure, for low operating power level with the power level less than 400W, the disturbance value is seemed consistent at no more than 4100 mV. However, as the operating power level is increased to a higher level, there is quite a significant rise in the disturbance value up to 11038 mV for the operating power level of 600W. Surprisingly, the value of disturbance reduced to 9537 mV for the operating power level of 800W. Oppositely, there are no noticeable changes on the standby mode as its value is consistent between 782 to 859 mV at frequency of 19.8 kHz.

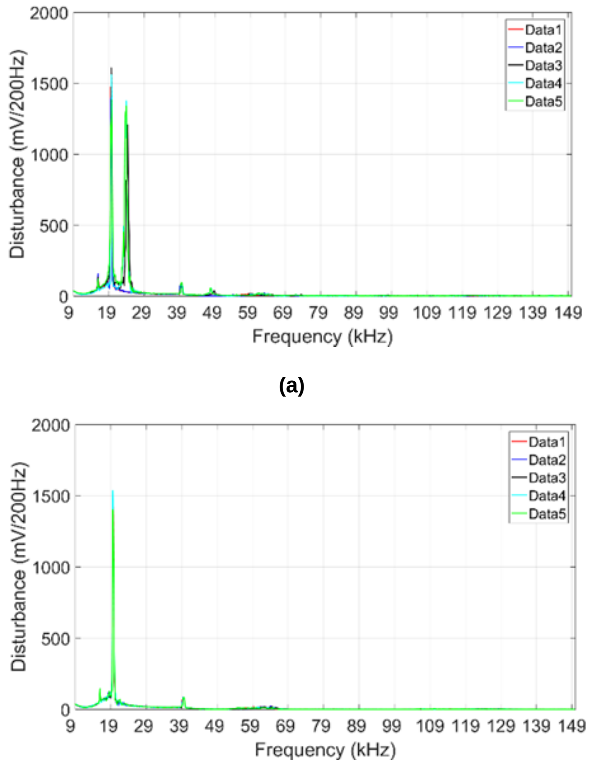

Figure 9. Disturbance profile of Brand B at 100W (a) upper cycle and (b) lower cycle

3.3. Disturbance Characteristics of Induction Cooker Brand B

Similarly, the second brand of the induction cooker is tested. For this brand B of induction cooker, there is six operating power level with two-cycle mode, operating by induction to generate the heat and standby mode as the cooker has reached the temperature setting.

Figure 9 shows the disturbance profile of brand B at the operating power level of 100W. As shown in the figure, the most dominant disturbance of the upper cycle is occurring at frequency 19.8 kHz with a value of 1608.58 mV. While the bottom cycle is at frequency 19.6 kHz with value 1537.011 mV. It can be seen the most dominant disturbance of each cycle has a little bit difference gap.

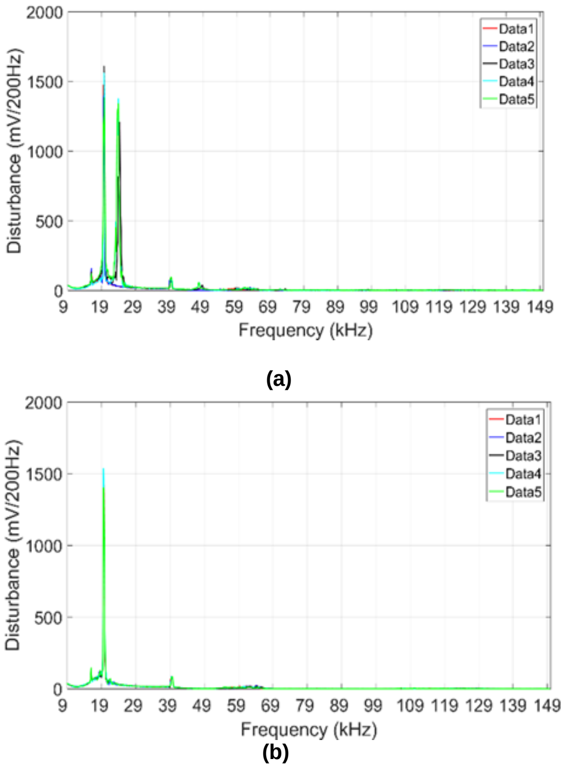

Figure 10. Disturbance profile of Brand B at 400W (a) upper cycle and (b) lower cycle

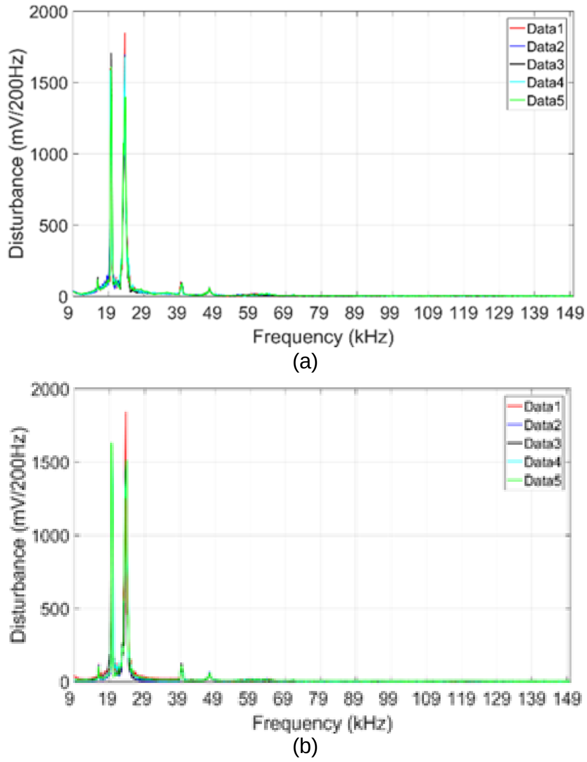

Figure 11. Disturbance profile of Brand B at 1000W (a) upper cycle and (b) lower cycle

Furthermore, Figure 10 shows the disturbance profile of brand B at operating power level 400W. From the data processing results, the most dominant disturbance of the upper cycle is happening at frequency 23.8 kHz with value 1644.558 mV. While the bottom cycle is at frequency 19.8 kHz with value 1652.626 mV. It can be seen the most dominant disturbance of each cycle has a small difference.

However, at power level of 1000W, the brand B induction cooker start to have different working characteristic as it started to induce for the heat production. The intensity of switching for the induction is more frequent than power level 400W. Before the operation change, the most dominant disturbance of upper cycle is at frequency 23.6 kHz with value 1845.098 mV. While, for the bottom cycle is at frequency 23.6 kHz with value 1838.169 mV. It can be seen there is just a little difference because this operation like a constant operation that has no cycle. This condition may occur due to the condition that the brand B is at its standby or idle condition. Detail of the disturbance profile for brand B at power level 1000W is shown in the Figure 11.

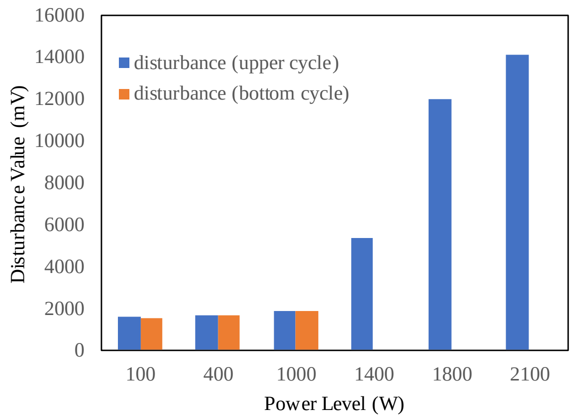

Figure 12. Disturbance profile of Brand B for all operation power level for upper cycle

Figure 12 shows the overall disturbance profile of brand B. There is a noticeable difference in the working cycle as at higher power level, the brand B is keep working to reach the desired setting. As the result during the measurement process there is only upper cycle available. At 1400 W the disturbance occurs at frequency 22.2 kHz with value 5361.026 mV. Furthermore, at power level of 1800 W it happens at frequency 20.6 kHz with value 12009.19 mV, and 2100 W at frequency 20.4 kHz with value 14.122.2 mV. As the power usage of induction cooker getting higher, the disturbance

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characteristics of induction cooker also getting bigger. This power quality phenomenon is quite similar to some previous studies, as mentioned in [9] [10] [14].

3.4. Discussion

It is worth to know the disturbance profile of both induction cooker for accurate mitigation strategy if the power quality is out of the electric grid standard. Yet, as there is a lack of standard regulates this power quality phenomenon, knowing the profile of each household appliance such as an induction cooker is one alternative toward the solution. By knowing the disturbance profile such as the dominant disturbance value at a specific frequency, then the correct solution, such as the use of a filter, could be utilized for the mitigation process, such as using active filter and line reactor methods [16].

The disturbance profile of both the induction cooker is shown in Figure 13. For brand A, during the low power level operation, such as 100 – 400W, the disturbance value seems constant at around 3922 mV. A similar trend also is shown by brand B for its low power level operation, such as 100 – 1000W. The average disturbance value is around 1700 mV. Further study is needed to find out the accurate reason for the double of disturbance value for brand A compare with brand B during their low power level. However, this might be occurring due to the characteristic component used by each brand. By their prices, brand B is triple higher compare to brand A. Consequently, the electric component quality of it may be better.

Furthermore, as both brands operate at higher power levels, the average gradient of disturbance value for brand A is much higher up to 260 % compare with brand B. The brand A gradient is 17.05 mV/W, whereas the brand B is 6.58 mV/W.

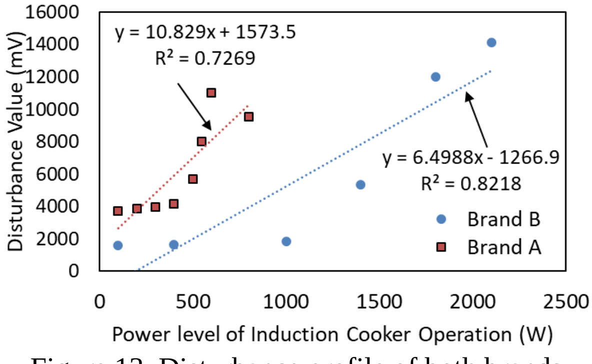

Figure 13. Disturbance profile of both brands

4. Conclusion

The measurement in this study gives us two disturbance characteristics of the induction cooker at frequency 9-150 kHz. The first type is the brand A induction cooker. It has a cycle of operation consist of conducting and standby mode. For each power level of operation mode, it generates disturbance. For brand A induction cooker, the most dominant disturbance occurs at the power level of 600 W at frequency 22.2 kHz. The disturbance value is 11037.38 mV or 11.04 V. On the other hand, for the brand B, the most dominant disturbance occurs at the power level of 2100 W at frequency 20.4 kHz with value 14122.20 mV or 14.12 V. The disturbance value that generated by both induction cookers is getting higher as the operation power level of induction cooker increase. Worth to be noted that both disturbance profiles share similar results as the dominant frequency is occurring near the 20 kHz, which it might be the switching frequency of most SMPS and inverter.

However, further study is needed to investigate the topology of each household appliance, including an induction cooker for knowing the exact contribution of its board switching frequency. By understanding the disturbance characteristic of each household appliance, the appropriate strategy of mitigation, such as the installation of an electric filter, could be used. This topic might also another scope for further study. By implementing a correct strategy, the power quality of the grid-connected PV system with a non-linear load attached would be improved in the near future.

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