An analysis on the impacts of load types, load capacities installed and power generated by the inverter towards disturbance on an on-grid solar power plant

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Abstract. Research regarding 9-150 kHz disturbance keeps increasing in the last few years, there are numerous reasons for this occurrence, including: the rise of the usage of electronic device that can generate high frequent disturbance such as fluorescent lights and solar inverters, PLC utilization used for communication on 9-150 kHz frequencies, and lastly the emergence of reports on disturbance impacts. In consideration of the rise of solar inverter usage in the last few years, this paper focuses research accounting impacts of load type, capacity, and power supplied by the inverter to disturbance in the 9-150 kHz frequencies. The system is connected with PLN, hence its categorization as ON-Grid. For power measurement facilitated with the PQA, and disturbance with the picoscope, which results are turned to frequency domain to ease the analysis. The results of the research show that the linear load of incandescent light bulb and nonlinear CFL bulb have similar trends. When the load capacity is increased, generated disturbance also increases linearly, a corresponding thing happening to power increase supplied from the inverter. The higher the power supplied from the inverter, the bigger the disturbance generated in the system. Both trends ensue on incandescent light bulb loads and fluorescent bulbs.

1. Introduction
Research regarding disturbance usually is conducted at 1 or 2kHz. This is because in this frequency band where most quality problems and regulations exist[1]. High frequency disturbance is low in voltage and current, and there haven’t been many issues reported in this frequency. However, recent years has shown an increase in disturbance research in the 9-150 kHz frequency band[2],[3]. This happens due to several major reasons; The first being nowadays a lot of electrical equipment contributes to high frequency disturbance, especially in the 9-150 kHz frequency range such as fluorescent lamp and distributed power source[4]. The second reason is that Power Line Communication that is used to communicate on distribution network uses the 9-95 kHz frequency band, where problems may appear due to similar frequency band at these high frequencies[5],[6]. The third reason is in recent years, the impact of high frequency disturbance is being reported[7]. Issues happening in many household appliances such as radio, television, etc. This particular frequency band also provides challenges regarding standardization of emission [8-10].
This paper focuses on disturbance generated in an on-grid solar power plant, which is a solar power plant that is connected to the grid. This is because in Indonesia, solar power has a potential up to 207.8 GW, the highest among other renewable energies. This also supports Indonesia’s cause to reduce greenhouse emission by 29% independently and up to 41% with the help of international help as per the Paris agreement. Furthermore, Indonesia also have a commitment to utilize renewable energy by 23% in their mixture of energy by 2025 and 31% in 2050. Indonesia is a country with thousands of islands, where solar power plant will contribute a lot in giving electricity to these islands, especially small and isolated islands. All these will contribute to the increase of usage for solar power plant in Indonesia, hence the focus on disturbance in this power generation.

2. Research Methodology

Research start by setting up the measurement devices. There are 2 measurement devices used in this research, the first one is power quality analyzer, which is used to measure power that is generated by inverter, power that is supplied by utility company, and power used by the load. The second device is picooscope, which is used to measure the voltage disturbance in the load. The picooscope are connected to a high pass filter with the purpose of filtering the fundamental voltage of 50 Hz as the amplitude of the voltage in 9-150 kHz is small. Measurement are done simultaneously using both devices for all variation of loads and power supplied through the inverter. Afterwards the data taken from the picooscope are fast fourier transformed using MATLAB to change from time domain to frequency domain to see in which frequency the disturbance is most dominant and to correlate their behaviour towards load type, capacities, and power supplied through an on-grid system. The flowchart below briefly explains the research method.

![Figure 1. Research Flowchart](image-url)
There are 3 important parameters that are analyzed in this paper, which is detailed in the table below.

**Table 1. Research Parameters**

| Parameter                                           | Analysis method                                                                                                                                                                                                 |
|-----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Load type towards disturbance                       | Varying linear and non-linear load type. For linear the load used is incandescent light bulb and for non-linear the load used is fluorescent light bulb                                                                 |
| Load capacity installed towards disturbance          | Varying load capacity, for incandescent light bulb starts from 100 Watt to 800 Watt, and for fluorescent light bulb starts from 250 watt to 1000 Watt                                                                 |
| Power supplied through inverter towards disturbance  | For each load variety, measurement is done when power supplied through inverter is at 300 Watt, 400 Watt, 500 Watt, 600 Watt and 700 Watt                                                                 |

The system and measurement device configuration can be seen as the picture below:

![System Configuration](image)

**Figure 2. System Configuration**

The measurement system is done on an on-grid solar power plant that is connected to PLN, Indonesia’s utility company. The utility company system will act as a secondary supply should the solar panels can’t supply enough power for the system, this happens during nighttime or when there is a cloud hovering above the panels etc. The load that is installed in this system are only loads that are being
tested, to ensure the disturbance produced are only impacted from the 3 defined parameters which is load type, capacities and power supplied through the inverter. The system has 1.2 kWp composed by 4 solar panel in series, each having 320 Watt peak. The inverter that is used is a 1.2 kW inverter. The picoscope is measuring the voltage disturbance on the load, while the power quality analyser is measuring power in the inverter to measure power supplied through the inverter, in PLN system to measure the power supplied through the utility company and in the load to measure total power used by the system. Measurement is done repeatedly on all varying loads and power supplied through inverter until enough data is available to analyse.

3. Result and Analysis

Analysis on the voltage disturbance is done in the frequency range of 9-150 kHz. As previously mentioned, the amplitude of voltage is this frequency range is extremely small, hence it is fast fourier transformed from time-based domain to frequency-based domain to ease analysis. An example of this graph can be seen in the picture below:

![Figure 3. Disturbance in Frequency Domain](image)

The graph on the left above shows the voltage disturbance when the system is loaded by 1000 Watt fluorescent light bulb when inverter is supplying the system for 300 watt, which means that the utility company is supplying the system for 700 watt in order to meet the demand. While graph right shows the voltage disturbance when the system is loaded by 100 Watt of incandescent light bulb when inverter is supplying the system for 700 Watt, which means 600 watt of those power are given to utility company. These graphs have 5 data in similar conditions for each graph. From these graphs it can be seen that each data has similar trends, just different amplitudes; the frequency that dominates the disturbance is at 19.8 kHz, where the analysis is focused on. Each data taken are converter like this, however only these 2 are presented in the paper as an example of the fast fourier transform.

In a PV system power that is supplied from the inverter are always fluctuating depending on sunlight. To see how disturbance is affected by power supplied through inverter data are measured for all type of loads during different times of day to vary the power that is supplied through the inverter. The graph below shows the correlation between power supplied and disturbance generated in 2 scenarios, linear load (incandescent lamp) and non-linear load (fluorescent lamp).
Figure 4. Disturbance Towards Power Supplied

Figure shows the correlation between high frequency disturbance and power supplied through the inverter. The difference is figure on the left load is incandescent lamp, while figure on the right’s load is fluorescent lamp. The blue line shows the power supplied through inverter, starts at 300 watt and ends at 700 Watt, increasing 100 watt for each points, while the red bar shows the average disturbance generated by the system at the corresponding point. The graph above shows that disturbance generated by linear and non-linear loads show similar trend, where as the power supplied through the inverter increases, the disturbance generated by the system also increases. However, the average disturbance generated by the fluorescent lamp are higher that incandescent lamp, this happens due to the non-linear properties of fluorescent lamp caused by ballast. For incandescent lamp, the lowest average disturbance is at 703 mV, while highest is at 842 mV, happening in 300 Watt and 700 Watt respectively, which means there’s an increase of 20%. For fluorescent lamp the lowest average disturbance is at 742 mV and the highest is at 964 mV, this translates to an increase of 30% in disturbance value. For incandescent lamp, the highest percentage change for average disturbance at 19.8 kHz happens from 400 Watt to 500 Watt, around 8.56 %, while for fluorescent lamp it happens from 300 to 400 Watt, around 10.75%.

In power system load always varies depending on what the consumer is doing. In order to see how load affects high frequency disturbance the load is increased incrementally. For incandescent lamp the load starts at 100 Watt, 300 Watt, 600 Watt and 800 Watt, while for fluorescent lamp the load starts at 250 Watt, 500 Watt, 750 Watt and 1000 Watt. The graph below shows the correlation between loads and disturbance generated.

Figure 5. Disturbance Towards Load

The graph above shows how load affects the disturbance generated in the system. Graph on the left represent incandescent lamp while graph on the right represents fluorescent lamp. The blue line shows the total power absorbed by the load and the red graph shows the average disturbance generated at 19.8
kHz. Based on both graph it can be seen that both incandescent and fluorescent lamp have similar trend, where as the load increases the disturbance generated is also increasing. During no load, the system generates disturbance averaging in 680 mV, for incandescent lamp the highest averaged disturbance happens at 800 watt for 812 mV, which means from no load to 800 watt there is an increase of disturbance for 19%, while for fluorescent lamp the highest disturbance happens at 1000 Watt for 954 mV, which means there is an increase of 40% from no load to 1000 watt. The highest percentage increase of disturbance at 19.8 kHz for incandescent lamp happens from 300 to 600 Watt, with a change of 8 %, while for fluorescent lamp the highest increase happens from 250 to 500 Watt, with a change of 13.16%.

4. Conclusion
This paper presents the analysis of disturbance in the frequency range of 9-150 kHz, how it is affected by linear and non-linear loads and how it is affected by varying power supplied by the inverter where the experiments are conducted on an on-grid PV system. Based on the measurement result some conclusion can be drawn: (i) voltage disturbance increase linearly as the inverter supplies more power, this is true for both incandescent lamp and fluorescent lamp; (ii) voltage disturbance increase linearly as the total loads are increased incrementally, this is true for both incandescent lamp and fluorescent lamp; (iii) incandescent lamp and fluorescent lamp show similar trend in regard to how the disturbance reacts to power supplied and load increased, the main difference is the average disturbance generated by fluorescent lamp are much higher than incandescent lamp due to non-linear properties.

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