International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 5 Issue 8 ǁ August. 2017 ǁ PP. 68-73

Harmonic AnalysisofDistribution System Due to Embedded Generation Injection

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ABSTRACT: The increased demand for electricity and the depletion of fossil energy sources are a challenge to exploit new and renewable energy sources. Relatively cheap renewable energy sources are Wind Power Plant (WPP) and Photovoltaic System (PV). Currently, many small scale generating plants are being evolved into conventional systems known as Embedded Generation (EG). EG as a source of electricity in the distribution system will affect the flow of system power, system reliability, voltage profile and others. Besides, with the placement of converter technology in WPP and PV system will give contribution of harmonic enhancement to the system. This paper presents the harmonic analysis of WPP and PV designs that are injected into conventional distribution system in one bus at Pujon feeder station Malang, Indonesia. The bus is chosen because in this area the need for electric power in the area is very high and the existing system has a harmonic value of 11%. Hybrid Active Filter (HAF) is designed to lower the voltage harmonics due to EG injection into existing systems without affecting harmonics in other buses. To analyze the harmonics in this study there are 4 scenarios offered: Scenario 1 starts with analysis on existing system, scenario 2 existing in WPP 2 MVA injection, scenario 3, injection1.3 MVA PV, scenario 4 injected EG (WPP and PV). The simulation result using PSCAD 4.5 shows in scenario 4 to generate harmonic voltage of 18.6% and after added with HAF, the harmonic value of the voltage becomes 2.434%.
Keywords: Embedded Generation, Harmonic, Photovoltaic System, Wind Power Plant.

I. INTRODUCTION

As 87.8% of electrical power requirement in Indonesia still utilizes fossil fuel, while the renewable energy usage is only in a level of 12.2%, i.e. water potential power (9.1%), biomass power (2.66%), wind power (0.002%), and solar power (0.16%) [1]. The renewable energy source utilizes natural resources by using small-scale power plant which is known as EG. Hakim [2] creates a feasibility study of hybrid power plant with maximum capacity of WPP for 2 MVA and of PV for 1.3 MVA located in Mount Banyak, Batu City. Jenkins [3][4] conducted a research about distributed small-scale power plant which is injected to the distribution system called the Embedded Generation (EG), which in turn helps electric power requirement.

Suyono [5] shows that injection from EG influences the power system reliability. It consists of voltage profile, power flow, losses on system, e.g. harmonic. Hasan [6] reduces harmonic value inside WPP using hybrid filter, i.e. serial connected active filter with shunt passive filter. Kalbat [7] analyzes total harmonic in PV system design and simulated with PSCAD software.This paper analyzes harmonic voltage from EG design with hybridized from 2 MVA WPP and 1.3 MVA PV. The design was simulated with PSCAD and the EG was injected into Pujon Feeder Distribution System.Leopold [8] uses hybrid active power filter for filtering the harmonic current in EG system by connecting active filter in series circuit with passive filter. Sushare [9] uses passive filter to eliminate load harmonic and active filter for improving the performance of passive filter. Tzung-Ling [10] designs Hybrid Active Filter Unit (HAFU) to supress harmonic resonance and to decrease hasrmonic distortion. The design of EG is then simulated by injecting hybrid system with bus in Pujon Feeder Station with 20 kV medium voltage. The design is expected to give solution to the lack of power supply and the high harmonic in Pujon Feeder Station.

According to the PT. PLN Gardu Induk Sengkaling, the Pujon Feeder Station still has power shortage and voltage harmonic as high as 11%, exceeding IEEE 519-1992 standard. Generally, the power shortage in Pujon is caused by the settlement located in hilly region, while the harmonic high value is mostly caused by tour sites operating many electric motors. Such problems lead this research into designing EG-injected grid system and adding HAF in order to decrease harmonic value, which in turn would resulting a reliable electrical power.

II. WIND POWER PLANT (WPP)

According to Ana [11], WPP is consisting of one or more wind turbine. The turbine selection will determine the quality of power produced. Patel [12] says that wind turbine in WPP system are arranged in parallel to produce electricity. The choice of turbine type is then based on wind speed, tower structure, count of rotor blades, the shaft, the generator, the fan, and the control system. Controlling the stability of power produced, it also requires anemometer, sensors, stall controllers, power electronics, battery, and mechanical transmission. Power electronic has a purpose to convert the electrical energy as needed. However, the components inside power electronics tend to rise the harmonic in WPP system.

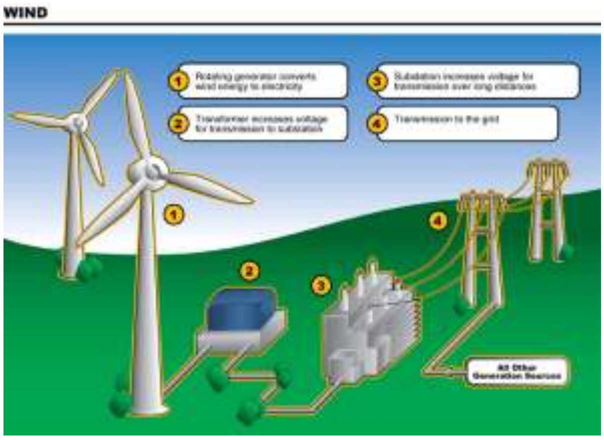


Fig.1. Working principle of WPP

Once the wind turns the blades of the turbine, the rotation is then transmitted to the generator rotor located behind the wind turbine. The generator converts this mechanical rotation energy into electricity, which generated by the alteration of magnetic flux in the stator and produces AC voltage and current. Prior to the distribution, it is usually first stored in the batteries, hence it needs rectifier for converting from AC into DC. The work of this rectifier plays a major role in harmonic generation in WPP system.Generally, the electrical system of the WPP is divided in two, i.e. fixed speed and variable speed. Considering the wind source in Mount Banyak, Batu as high as 12 m/s and located on hilly location, the design uses fixed speed turbine and 3-blade horizontal axis. With this conversion from AC to DC, further analysis about voltage harmonic caused by the conversion is required.

III. PV SYSTEM

Patel [12] says that the PV system main components are PV cell module, solar radiation, and the module surface temperature. P System possesses an ability to convert photon from solar radiation into DC power. The amount of voltage and current depends on the intensity of photon hit the PV cell surface. With the intensity of the solar rays on the earth surface of 1000 watts with 25 °C, the PV is designed to have 1.3 MVA capacity. The electricity generated by the PV is then charged into battery, and then converted into AC by inverter to the transformer and injected directly into Pujon Feeder Station distribution grid.

The presence of inverter, however, leads to harmonic voltage increasing in the system. It can be reduced by filter. The main purpose of the filter is to reduce the amplitude of specific frequencies of a current or voltage. On the other side, installation of harmonic filters in the power system makes suppression in harmonic current spreading to the entire grid.

IV. SIMULATION RESULT

4.1 Existing

The existing data used is originated from Sengkaling Relay Station, which has 2 150/20 kV transformers with 30 MVA and 60 MVA capacities, respectively. The Pujon Feeder Station is a feeder in Sengkaling Relay Station which is supplied from transformer of 150/20 kV 300 MVA with 300 A nominal load capacity. The feeder station installs distribution relay as many as 71 units with each capacity ranged from 25 kVA to 250 kVA.

The Pujon Feeder Station currently operates in average load on 67^{th} bus with voltage harmonic value as high as 11%. It exceeds the IEEE 519-1992 standard, which is 5% on 20 kV. By using data from Pujon Feeder Station, simulation provides 10.853% harmonic voltage and 27.5% total harmonic distortion (THD). Visually, simulated harmonic voltage and THD is shown in Figure 2. The primary side of 67^{th} bus experienced voltage drop from 20 kV to 17 kV, as shown in Figure 3.

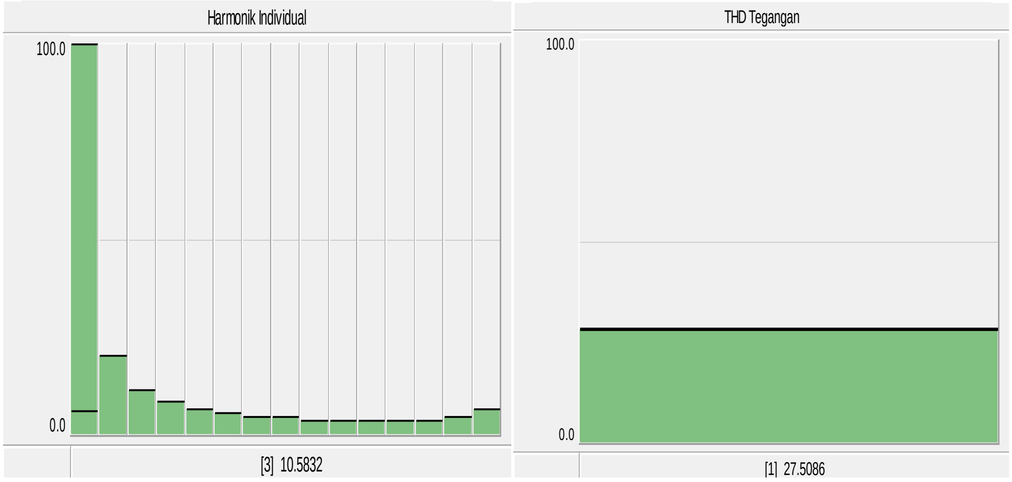


Fig.2. Harmonic voltage graphical representation (*existing*)

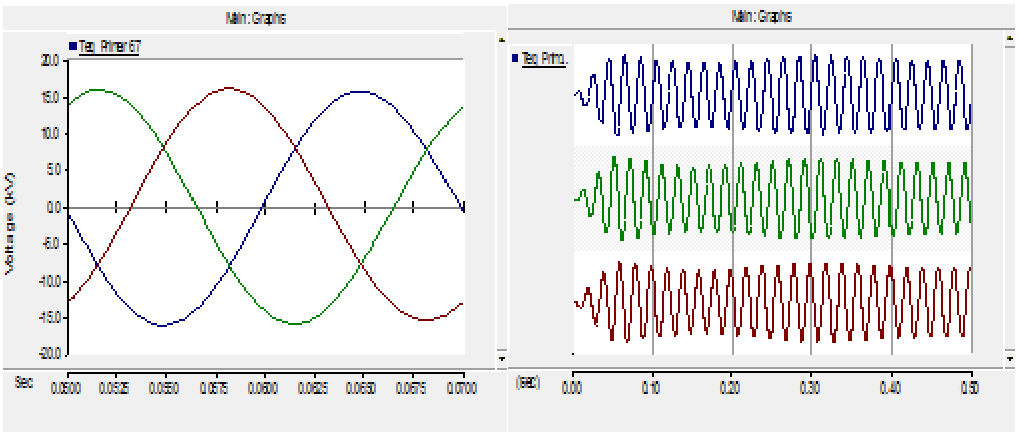
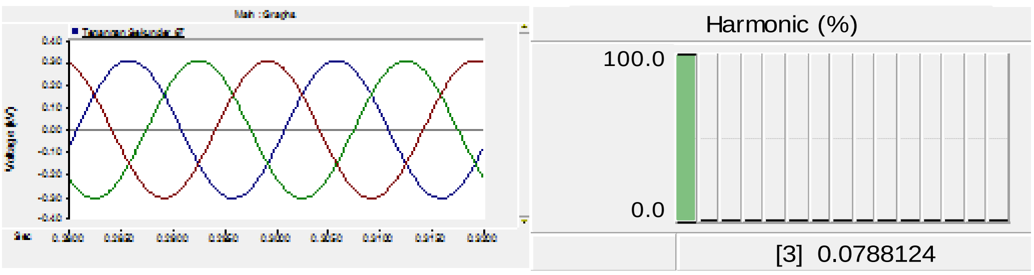


Fig.3. The 67th bus voltage in graphical representation (*existing*)

4.2 Existing + WPP 2 MVA

The second scenario is to design 2 MVA WPP and connect it with the existing 20 kV. WPP is then connected to the existing without both battery and control system. The 2 MVA WPP is designed with output voltage 690 V and then connected to the step down transformer 0.69/0.38 kV. The WPP system is then injected directly to the 67th bus in the secondary side on 0.38 kV. And the simulation results in voltage harmonic less than 1%, 0.3753 kV voltages and 1.2 MW power. The harmonic value in this scenario is small because of no control system connected to the system. The graphical representation of the voltage and the harmonic is shown in Figure 4.



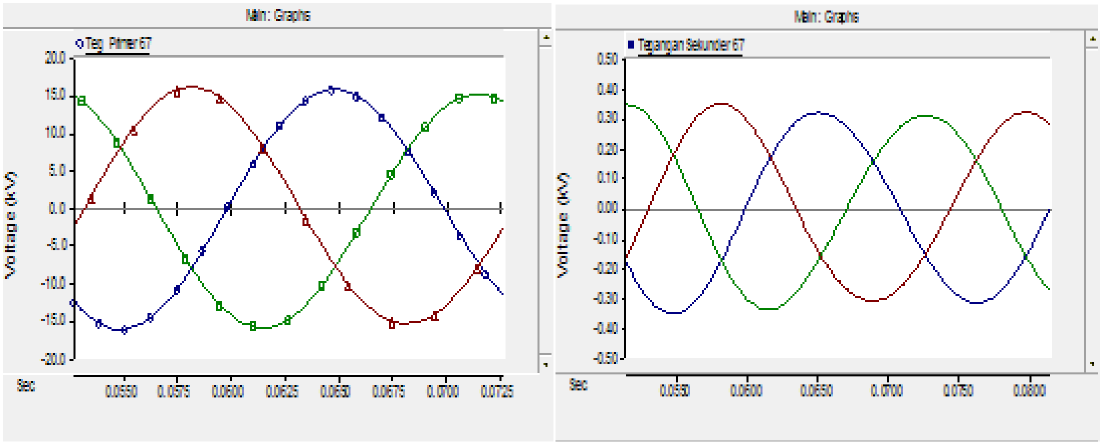
(a) (b)

Fig.4.(a) Graphicalvoltageon bus 67th, (b) Harmonic on bus 67th

4.3Existing + PV 1.3 MVA

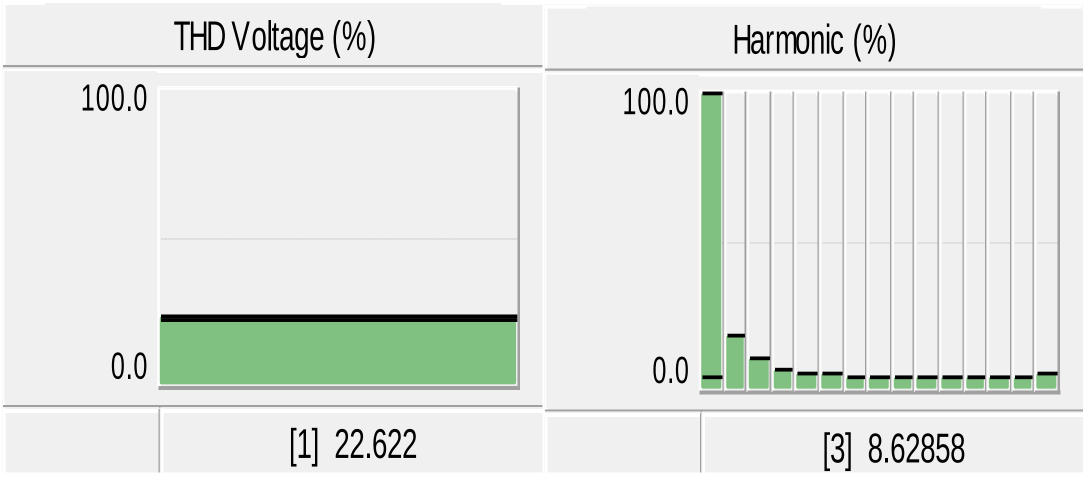
The third scenario is to connect between Pujon existing feeder and PV system. It joins 1.3 MVA PV system into 67th bus on Pujon Feeder Station. This bus is selected since it is located in tourist area which has high power demand and high harmonic. The output of the PV system will be 0.83 kV DC and 1.3 MVA and then stored in the battery. The battery power drain is then converted into AC 380 V, and converted again into

0.295/16.53 kV with 0.9 MW power as displayed in Figure 5. This system produces voltage harmonic 8.62% and total THD of 22.622% as shown in Figure 6.



(a) (b)

Fig.5.(a) Primary Voltage , (b) Secondaryvoltage on bus 67th



(a) (b)

Fig.6 (a) THD Voltage, (b) Harmonic on bus 67th

4.4 Embedded Generation (Existing + WPP + PV)

The fourth scenario is to join WPP and PV design into existing. Prior to existing injection, WPP and PV are joined together, and the WPP system has the output converted into DC by using rectifier. The output voltage from WPP is then combined with PV output and DC link 1.76 F. The DC current is then stored in battery with output voltage of0.453 kV. Just beforeinjection to the existing, the DC is supplied to the inverter and passive filter to generate AC power of 0.3781 kV. Figure 7 displays the voltage before and after filtering.

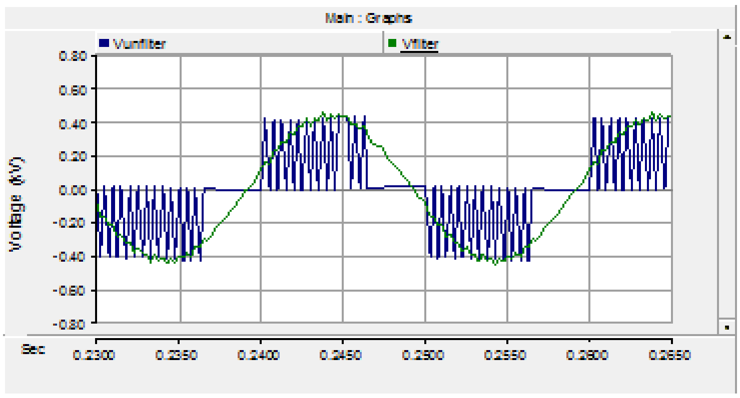
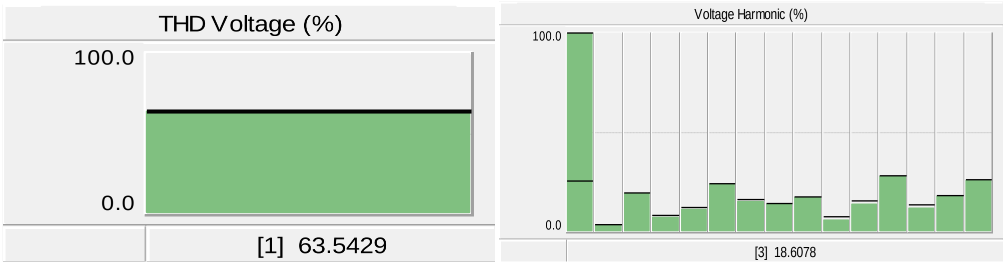


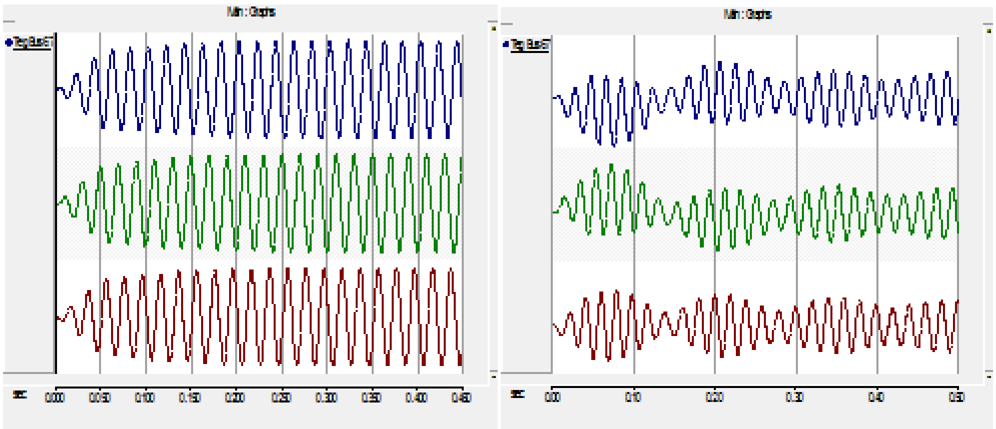
Fig.7 Hybrid output voltage of the system

The hybrid of WPP and PV is then connected to the 0.38/20 kV step up transformer, and injected to the 67th bus. As shown by the simulation, the injection of the hybrid system produce 18.6% voltage harmonic and 63.54% THD, and visually can be obtained from Figure 8. Generally, the EG system generates voltage of 0.3115/17 kV with voltage dropping more than 10% and 3.08 MW power. Figure 9(a) shows the graph of voltage before injection of hybrid system, and Figure 9(b) shows the voltage after.



(a) (b)

Fig.8 (a) THD Voltage, (b) Harmonic on bus 67th



(a) (b)

Fig.9 (a) Voltage before injection, (b) Voltage after injection

The simulation result suggests that the hybrid injection produce distorted voltage, so it requires appropriate filter to obtain sinusoidal voltage, as shown in Figure 8 and Figure 9. The installation of filter offered is using Hybrid Active Filter (HAF) from the secondary side of 67th bus.

4.5 Embedded Generation (Existing + WPP + PV)by HAF

The final scenario is to join EG to HAF system. HAF is a combination of active and passive filter. Akagi [13] stated that active filter works to improve the passive filter performance. HAF is connected to the primary side of 67th bus and it's shown in Figure 10. Once the existing injected by EG, then the entire system is then connected to the HAF. Simulation result before HAF showed 17.82/0.3374 kV voltage, 18.6% voltage harmonic, and 63.54% THD. After HAF, simulation produces 17.82/0.3373 kV voltage, 2.43441% voltage harmonic, and 23.4316% voltage THD. Table 1 shows distinction between the five different simulation.

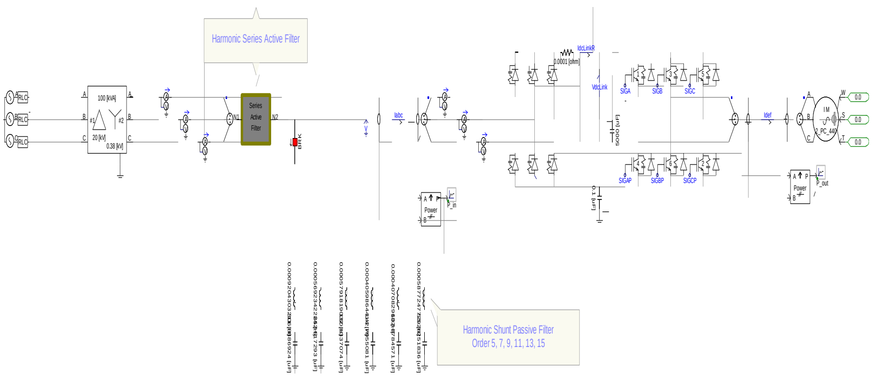


Fig.10 Design Hybrid Active Filter (HAF)

Table 1. Embedded Generation (EG) Injection System Scenario

Scenario	Existing bus 67	WPP 2 MVA	PV 1.3 MVA	Harmonic (%)	Harmonic (%)	
					Passive	Active
1	√	-	-	10.583	4.7	-
2	√	√	-	0.078	-	-
3	√	-	√	11.0066	5.9	-
4	√	√	√	18.6	6.72	2.43

V. CONCLUSION

The results of the analysis and simulation with 4 scenarios can be summarized as follows:

1. The harmonic analysis is performed to find the voltage profile, harmonic voltage and THD voltage.
2. In scenario 1, has a harmonics voltage of 10.583% and after the connect the passive filter down to 4.7%
3. Scenario 3, has a harmonic voltage of 11.0066% and after connected the passive filter drops to 5.9%.
4. Simulation in scenario 4 is generated HAF installation on EG system hence it will decrease harmonic voltage value from 18.6% to 6.72% if only passive filter function. When the active filter is run as well then the harmonic voltage becomes 2.43%.
5. The use of HAF generally improves the harmonic value of voltage on the system.

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*Achadiyah A.N. "Harmonic Analysis of distribution System Due to Embedded Generation Injection." International Journal of Research in Engineering and Science (IJRES) 05.08 (2017): 68-73.