Analysis of Harmonic Effect of Photovoltaic Integration into Medium Power System

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Abstract. Renewable Energy is starting to grow rapidly, the use of solar energy in Indonesia has a good development. According to the grid code issued by the national utility company, the maximum standard harmonic limit is 5%. Harmonic is mostly caused by non-linear loads that form a distorted sine wave, which leads the equipment to become hotter faster, adding losses and reducing the equipment lifetime. The simulation method uses ETAP software to obtain values from Total Harmonic Distortion (THD) on the 20kV and 150 kV Beta substations sides with several scenario simulations of photovoltaic power plant integration with a capacity from 5 to 20 MWp with multiple of 5. The simulation results have shown that the maximum THDv value in the scenario at 20 kV Beta substation is 0.26% and at 150kV Beta substation is 0.1%. This value is still below the standard limit, so by the integration of PV plant, system still operates securely.

1. Introduction
Harmonic is one of the important problems in quality power system, which is the distorted sine wave resulted by nonlinear electric components with multiples fundamental frequency. Harmonics can harm the system if the existing value exceeds the standard limit that has been set. Harmonic can be known in the form of waves with different frequencies that produce new frequencies by multiplying the integer base frequency which has a boundary value, in the form of an original wave where the multiplier is used as a harmonic sequence number [1-3]. For example, the basic frequency of an electric power system is 50 Hz, so the harmonics are both waves with a frequency of 100 Hz, the third harmonic is a wave with a frequency of 150 Hz and so on. These waves then hitch in the pure wave so that an imperfect wave is formed which is the sum between instantaneous pure waves with harmonic waves [5]. This harmonic is caused by a non-linear load on an electric power system that makes the system current become very distorted with a very high THD (total harmonic distortion) value [4-6].

Linear load indicates the load class, which, if supplied by a sinusoidal source at fundamental frequency, the resulting form is a fundamental sinusoidal current [7-9]. Substantial loads in the form of urban and commercial loads, synchronous motors, and induction motors are examples of linear loads. In contrast to linear loads, electronic loads such as drive speeds that can be adjusted as desired are examples of nonlinear loads, which produce harmonic values [10].

The percentage value of current harmonic content (THD) in an electric power system causes some serious harmonic problems in the system, such as the occurrence of harmonics on the load side which results in overheated on the equipment causing derating of the insulation which can affect the
quality of the equipment so that it breaks down quickly, resonance on a system that damages capacitor compensation, makes the system's power factor decrease, increases losses on the system network, and can reduce the usage period of the equipment, the section above illustrates the ineffective use of electrical energy [9]. Therefore, the harmonic value that occurs in a system can be calculated with the general parameters used to determine the value of harmonics, such as THD (Total Harmonic Distortion). The purpose of this paper to find out the value the harmonic effect of the system from PV has on the system at the Beta Substation. Therefore, this paper will explain the harmonic impact that occurs with the limits of the permitted values.

2. Materials and methods

Figure 1. Flow chart of the study

Figure 1 explains the steps in the study to get the Total Harmonic Distortion Voltage. This experiment was carried out by determining the bus on the network according to the Single Line Diagram of the Alpha Solar Power Plant.
The scenario 1, 2, 3 and 4 are made based on varying PV capacities from 5 MWp, 10 MWp, 15MWp, and 20 MWp, respectively, which is installed in HV and LV side of Beta Substation, namely 20 kV and 150 kV. The value of Total Harmonic Distortion is derived based on simulation in ETAP, and the value will be compared to the grid code’s standard. Thus, it can be said that the THD value can be used as a parameter that describes the deviation of the wave of non-linear load from the fundamental waves. In other words, THD value is a comparison of the value of harmonic RMS to fundamental values as follow,

\[
THD = \sqrt{\frac{\sum_{h>1} v_{h}^2}{v_1}} 
\]

\[
THDv = \frac{\sqrt{v_2^2 + v_3^2 + v_4^2 + \cdots + v_n^2}}{v_1} 
\]

Disturbances that occur due to wave distortion can be in two forms, namely harmonic current and harmonic voltage. Harmonics can damage and interfere with loads that have a high sensitivity level so that the waves are distorted so the study of harmonics is a concern in the world of industry. The standard harmonic use a predetermined value limit pre-approved by the IEEE. So the following table is the harmonic limit which can be seen in Table 1.
Table 1. Standard Voltage Harmonics (IEEE Standard, 1992)

| PCC Voltage Vn (kV) | THDv (%) |
|---------------------|----------|
| Vn ≤ 69             | 5.0      |
| 69 < Vn < 161       | 2.5      |
| Vn > 161            | 1.5      |

3. Simulation results and discussion

![Figure 3](image)

**Figure 3.** The THDv results of 2 conditions for Scenario 1: a) 150kV Beta Substation b) 20kV Beta Substation

![Figure 4](image)

**Figure 4.** The THDv results of 2 conditions for Scenario 2: a) 150kV Beta Substation b) 20kV Beta Substation

![Figure 5](image)

**Figure 5.** The THDv results of 2 conditions for Scenario 3: a) 150kV Beta Substation b) 20kV Beta Substation

![Figure 6](image)

**Figure 6.** The THDv results of 2 conditions for Scenario 4: a) 150kV Beta Substation b) 20kV Beta Substation
Table 2. Simulation Results

| Bus ID                | THDv 1 | THDv 2 | THDv 3 | THDv 4 |
|----------------------|--------|--------|--------|--------|
| 20kV Beta Substation | 0.06%  | 0.14%  | 0.20%  | 0.26%  |
| 150kV Beta Substation| 0.03%  | 0.05%  | 0.07%  | 0.10%  |

Table 2 shows the values of THDv for each scenario at 20 kV and 150 kV Beta Substation. The PV plant capacities are varied from 5 MWp to 20 MWp with multiple of 5. The simulation results for the harmonics in 20kV and 150kV in each scenario shows the value does not exceed the limit of the predetermined value. For scenario 1, THDv at 20 kV Beta Substation is 0.06% and THDv at 150kV Beta Substation is 0.03%. The scenario 2 was carried out with a 10 MWp capacity PV integration. There is an increase in the results obtained, the THDv value at 20 kV Beta Substation is 0.14% and at 150kV Beta Substation is 0.05%. By integrating 15 MWp capacity for scenario 3, THDv at 20kV Beta Substation is 0.20% and for the value generated at 150kV Beta Substation is 0.07%. Finally, the last experiment with the largest power capacity in scenario 4, THDv value at 20kV Beta Substation is 0.26% and at 150kV Beta Substation is 0.1%.

4. Conclusions

From the results of this simulation, it shows that the highest harmonic voltage ratio (THDv%) in 20 kV and 150 kV Beta substations are 0.26% and 0.1% respectively, which is happened when integrating 20 MWp PV plant to Alpha grid. Installation of PV system in Alpha grid from 5 MWp to 20 MWp capacities, which is specifically integrated into Beta substation, still provides a secure operation of power system. The resulting THD value is still accepted as stated in IEEE standard. It can be seen from the results of the simulations that the PV capacity affects the generated THDv value.

References

[1] Barr R A and Gosbell V J 2014 Power System Harmonic Voltage Limits for the Future 16th Int. Conf. on Harmonics and Quality of Power.
[2] Clua J and Jordi O 1998 Load modeling for unbalanced harmonic power flow studies 16th Int. Conf. on Harmonics and Quality of Power.
[3] Su W, Li Z and Shao Z 2014 The harmonic calculation model of non-linear load China Int. Conf. on Electricity Distribution.
[4] Talebkah A, Shadlu M S and Fatemi S M 2019 Control Strategy of a Single Phase Active Power Filter with Adjustable DC Link Capacitor Voltage for THD Reduction in Non-linear Loads 10th Int. Power Electronics, Drive Systems and Technologies Conf.
[5] Peter A G and Saha A K 2019 The Impacts of Harmonics Reduction on THD Analysis in HVDC Transmission System using Three-phase Multi-Pulse and higher Level Converters Southern African Universities Power Engineering Conf. /Robotics and Mechatronics / Pattern Recognition Association of South Africa
[6] Corso A, D’Agostino F, Gardella D, Mazzucchelli M and Silvestro F 2016 Analysis of the impact of AFE active front end on the THD on a shipboard power system: A comparison study using different simulation approaches Int. Conf. on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles & Int. Transportation Electrification Conf.
[7] Jabbar R A, Junaid M, Masood M A and Akhtar K S 2009 Impacts of harmonics caused by Personal Computers on distribution transformers 3rd Int. Conf. on Electrical Engineering
[8] Larez A J and Pereyra L E 2006 Evaluation Power Quality in Electrical Utilities Companies Transmission & Distribution Conf. and Exposition: Latin America
[9] De Abreu J P, De Sa J S and Prado C C 2003 Harmonic Voltage distortion in isolated electric systems 7th International Conference. Electrical Power Quality and Utilisation pp. 469-472.
[10] Raj C T, Agarwal P, Srivastava S P 2006 Performance Analysis of a Three-Phase Squirrel-Cage
Induction Motor under Unbalanced Sinusoidal and Balanced Non-Sinusoidal Supply Voltages

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