International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 23621-23629

http://www.ripublication.com

A Study of Harmonics In PV-Wind Turbine Microgrid System

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Abstract

This paper concerns with significant role of power quality, particulary harmonic, in the PV-wind power generation system. These are two most popular renewable energy sources hoped can overcome energy needs in the future. Photovoltaic and wind systems have been widely utilized in the generation of electrical energy, either at home or abroad. In this research, The PV-Wind microgrid system built consists of six different generator systems (i.e. one generator, two wind turbines and three PV panels), trafo and load system. Several factors which generate harmonic on PV-Wind power generation system are solar irradiation, wind speed, inverter/ converter and generator. This paper also analyzed load flow in the system either when they are connected or not connected (islanded) to the grid.

Keyword: Harmonics, microgrid, photovoltaic, wind turbine.

Introduction

Solar and wind energy, among several renewable energy resources, are the most essential and the most promising way because of abundance and easy to access. An interesting method of power generation system are provided by photovoltaic and wind turbine technology and fulfills the clean energy and sustainability criteria. Some previous researchers have focused on efforts to improve the efficiency of both generator systems and maximize energy production through reduction in power losses and also optimize the solar radiation received by PV [1][2]. There are several factors that affect the level of efficiency and performance of PV-wind turbine systems[10][11]. The most significant factor in the operation of the PV is the environmental condition and it can cause serious problems related with the efficiency and power quality response of the overall system[7][8][9]. According to some previous researches show that solar irradiance fluctuation, environmental temperature and characteristic of PV system are parameters that influence the power quality of photovoltaic systems, as stated by reference [6] that low solar irradiance has a significant impact on the power quality of the output of the PV system.

Meanwhile, power quality of the wind turbine are dominantly influenced by wind speed, converter and type of generator[3][4][12]. The power quality can be said good when the sinusoidal voltage and current output of the power system is free from harmonics, interharmonics and ultimately voltage distortion.

In general, harmonic currents and voltages generated by the power plants can decrease power quality and downgrade the reliability and safety of the electrical equipments [1][3]. The harmonic currents can also cause interference on telecommunication systems, some errors in measuring devices, excessive heat in the breaker power equipment so that it can disconnects itself, the control system is locked by itself, and many more problems posed.

In this study, the harmonic and load flow behaviour of PV-wind turbine microgrid system has been simulated, observed and investigated either when connected or not connected to the grid.

Standards of Harmonic Limits

Harmonics is a phenomenon in which the waveforms of the high frequencies (such as 100Hz, 150Hz, 200Hz, and so on) are multiples of fundamental frequency (50 Hz)) that can interfere continuity and quality of power supply. In other hand, it causes the current and the voltage waveforms which is ideally pure sinusoidal will become disabled as a result of harmonic distortion. The IEEE Standard 519-1992 issues recommended practices and requirements for Harmonic control in electrical power systems to determines the limits of harmonic voltage and current at the point of common coupling (PCC) between end user and distribution utilities. The method used in the standard needs the participation of both end users and utilities. Tabel I describes the limits established by the standard. According to this, producers must provide to the customer that voltage and current total harmonic distortion are equal to 5%. While for maximum individual harmonic components, the limit is 3% for voltage source lower than 69KV. Table II shows standard of current distortion, where the limits of current distortion vary based on the short circuit strength of the system they are being injected into. In principle, the more the system can handle harmonic current, the more consumer is allowed to inject[6][9].

Table 1: Harmonic Voltage Limits

Bus Voltage	**Individual Voltage Distortion (%)**	**THD (%)**
≤ 69 kV	3	5
69,001 kV - 161 kV	1,5	2,5
≥ 161,001 kV	1	1,5

Table 2: Harmonic Current Limits

Maximum harmonic current distortion in percent of I_L						
I_{SC}/I_L	**Individual Harmonic Order (odd harmonics)**					
	<11	**11≤h≤17**	**17≤h≤23**	**23≤h≤35**	**35≤h**	**TDD**
< 20[*]	4	2	1,5	0,6	0,3	5
20 – 50	7	3,5	2,5	1	0,5	8
50 – 100	10	4,5	4	1,5	0,7	12
100 – 1000	12	5,5	5	2	1	15
> 1000	15	7	6	2,5	1,4	20
Even harmonics are limited to 25% of add harmonic order above.						
Current distortion that result in DC offset, i.e half-wave converters, are allowed						
[*]All electrical generation equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L						
Where : I_{SC} = Maximum short - circiut current at PCC I_L = Maximum load current (fundamenta frequency component) at PCC TDD = Total demand distortion						

Meanwhile based on the European standard EN50160 (IEC 50160), supported by most European Grid Codes, that voltage characteristics of electricity supplied by public distribution systems should not exceed 8 % for total harmonic distortion limit, including up to the 40th harmonic.

Total Harmonic Distortion (THD) is the percentage of total harmonic component to the fundamental component. THD can be written as[13]

$$THD = \frac{\left(\sum_{n=2}^{k} {U_n}^2\right)^{\frac{1}{2}}}{U_1} \, x100\% \tag{1}$$

Where
U_n = harmonic component
U_1 = the fundamental component
k = the observed maximum harmonic components

Total Demand Distortion (TDD) is the ratio of the rms value of the harmonic current components to maximum demand load current. TDD can be formulated as follows[13]

$$TDD = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_L} \qquad (2)$$

Where I_L is the maximum demand load current (15 or 30 min demand) of the fundamental frequency at the PCC that is calculated as the average current of the maximum load for the previous twelve months.

Topology of Microgrid System

In this study, PV-wind turbine microgrid system has been simulated and tested which analytically consist of three PV panels, two wind turbines and one generator , the configuration of microgrid is shown in figure 1. The system has been set on islanded and connected conditions. Transformer used has a delta-wye winding type with capacity of the transformer is 400kVA and be able to reduce the voltage from 20kV to 0.4kV. Detailed microgrid specifications are presented in table III and IV below.

Table 3: Microgrid Generator Specifications

Bus	**Generator**	
	Type	**Capacity (kW)**
1	Generator	30
2	*Wind Turbine*	5
3	*Wind Turbine*	20
4	PV	10
5	PV	3
6	PV	20

Table 4: Microgrid Cable Specificatons

Number of Cable	**Specification**	
	Type	**length (m)**
1	AL 3/C 120mm^2	35
2	CU 3/C 6 mm^2	20
3	CU 3/C 120 mm^2	100
4	CU 3/C 25 mm^2	20
5	CU 3/C 35 mm^2	20
6	CU 3/C 25 mm^2	30
7	AL 3/C 120mm^2	35

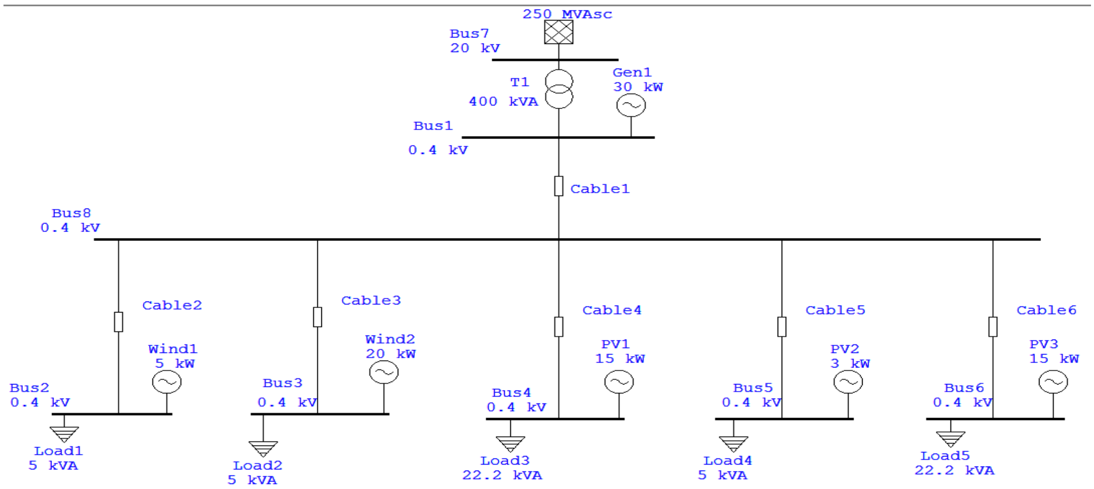

Figure 1: Photovoltaic – Wind Turbine Microgrid Single Line Diagram

Results and Discussion

This paper analyzes the load flow and harmonics in the microgrid system, either connected or not connected (islanded) to the grid. The simulations conducted use ETAP 7.0 which the contribution of harmonics in PVs refer to the reference[9], these are affected by two factor including solar irradiation and inverter, while the wind turbines use the results of research conducted by the GA mendoca, et al[13] where harmonic behaviour depends on wind speed and converter. The following is simulation results including magnitude of buses, power factor (PF), THD and TDD, respectively.

Table 5: Generator Data On Islanded Phase

Plant	Operation mode	P (kW)	Q (kVar)
Gen1	Swing	30	0
Wind1	Mvar Control	2	1,2
Wind2	Mvar Control	12	7
PV1	Mvar Control	8	4.95
PV2	Mvar Control	1.5	0.9
PV3	Mvar Control	8.5	5.25

Table 4: Current & Power Factor Of Microgrid System

Cable	Current (A)		PF (%)	
	Islanded	Connected	Islanded	Connected
1	31,4	84,8	85.0	85,5
2	3,8	7,1	87,1	86,5
3	12,9	7,1	86,3	86,5
4	18.4	31,8	85.0	85,1
5	4.6	7,1	86.8	86,5
6	17.5	31,7	85.0	85,1

Table 7: Magnitude of Bus Voltage

Bus	% Magnitude of voltage	
	Islanded	Connected
1	100	99,55
2	99.75	98,98
3	99.97	99.12
4	99.74	98.96
5	99.84	99.14
6	99.68	98,85
7	100	100
8	99.86	99.18

Table 8: Voltage Thd of Buses

Bus	%THD		Bus Voltage
	Islanded	Connected	
1	4.21	0,01	0,4 kV
2	4.21	0,01	0,4 kV
3	4.21	0,00	0,4 kV
4	4.20	0,02	0,4 kV
5	4.21	0,01	0,4 kV
6	4.20	0,02	0,4 kV
7	4.21	0,00	20 kV
8	4.21	0,02	0,4 kV

Two cases have been simulated in this paper, they are islanded phase which Gen1 converted into a swing mode and the other generators are operated at MVar control mode and connected phase where all plants will be disabled and save the energy, A power grid of 8,963 MVAsc is used to supply the existing loads (the data taken from segara madu grid, Indonesia).

Table 9: Tdd of System

Cable	Isc (A)	I_L (A)	Isc/I_L	%TDD	
				Islanded	Connected
1	783	31,4	24.936306	5,68	0,00
2	748	3,8	196.84211	1,44	0,00
3	769	12,9	59.612403	5,53	0,00
4	777	18.4	42.228261	5,84	0,00
5	775	4.6	168.47826	5.24	0,00
6	773	17.5	44.171429	6.12	0,00

It is very important to recognize, however, that power factor is a major consideration in the analysis of harmonics because the two power quality parameters influence each other. Table VI shows that power factor ranges from 85% to 87,1% for islanded mode and 85.1% to 86.5%, which is still within the tolerance limits determined by the state electricity company '(PLN). This means that the sources of harmonics, both PV and wind turbines, do not significantly reduce the power factor.

Performance of load flow of the system is shown in the table VII, where all buses have voltage percentage above 99% for islanded and more reliable than connected mode, even the best performance is achieved by bus 1 and 7 with 100%, indicating that the system is working properly.

As seen from table VIII, that voltage THD range is from 4.20 – 4.21% for islanded, the results conforms to requirement (see table I, maximum voltage THD allowed is 5 % for ≤ 69 KV). In other hand, the connected mode shows that voltage harmonic generated by system is very small with range from 0 to 0.02%. This indicates that the largest harmonic contribution is PVs and wind turbines. Finally, the current harmonics of the microgrid system can be determined by the calculation of the ratio between the short circuit current (Isc) and the nominal current (IL) flowing in the channel. Based on table IX, total demand distortion (TDD) of all channel are below acceptable limits of standard, even all TDD of connected mode is zero. Thus, the system has high reliability and safety.

Conclusion

According to the simulation and analysis, there are several conclusions. First, Active and reactive power control in renewable energy power plant, which in simulation using a generator on MVar control operation mode, is well. It is proven by indicators of good power quality. The second, two modes of the system has been simulated and analyzed, the performance index of power quality of both in accordance with the requirements of the standard, where the power factor and voltage magnitude is above the standard, whereas THD and TDD is below the allowed tolerance limit. Third, harmonics generated by the system are primary affected by PV and wind turbines contribution, where they are significantly dependent on solar irradiation, wind speed, inverter and converter.

Acknowledgment

The authors would like to acknowledge the facilities support provided by Power System Simulation Laboratory, Electrical Engineering Department, Sepuluh Nopember Institute of Technology surabaya, Indonesia.

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