THE IMPACT OF EMBEDDED GENERATION DUE TO HARMONIC PERFORMANCE

AZIAH KHAMIS
MATTHEW ARMSTRONG
MARIZAN SULAIMAN

(2009 Third Asia International Conference on Modeling & Simulation)

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

The Impact of Embedded Generation due to Harmonic Performance

Aziah Khamis, Matthew Armstrong, Marizan Sulaiman
Department of Power Industry,
Universiti Teknikal Malaysia Melaka (UTeM),
75450 Ayer Keroh, Malacca, Malaysia.
Email: aziah@utem.edu.my/ azi_ah2000@yahoo.com

Abstract

The paper investigates the most suitable location of inverter connection installed into the distribution line feeder. Thus, it can reduce losses, control voltages as well as the protection system [1]-[8]. Besides, it is more focused on mitigated a whack-a-mole phenomenon due to its fifth and seventh harmonics. Whack-a-mole phenomenon occurs as an active filter or passive filter installed on the long feeder line. It effect harmonic voltage where increase on some busses and decrease on other busses, especially at point of installation [9]. In this paper, the inverter replaced by directly connected with the current source. Thus, parallels current source with combination of fundamental, third, fifth and seventh harmonic frequencies were tested. From the analysis, the best location of inverter current source should be at least $\lambda/4$ *from end bus [10]. Thus, it proves by looking into its harmonic voltage, harmonic current and total harmonics distortion (THD) performance.*

1. Introduction

Generally, many distributed generation (DG) such as photovoltaic array should be connecting with power electronic devices as shown in Figure 1. It is use to inject unity power factor sinusoidal current into the grid. Besides, it used to convert DC power into AC. The voltage level as well as the frequency had to be match with the power of the distribution line feeder. This additional power converter should represent minimum impact to the harmonics and it should not generate significant level of harmonics.

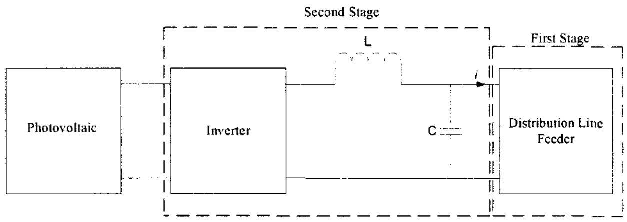


Figure 1: Block diagram of DG network system

In this paper, the modeling and the parameter of distribution line feeder is base on Wada et al [9]. It used lumped-circuit with per-kilometer parameter. The model is set combination of capacitance and inductance that is uniformly discrete in the radial trunk feeder without any branch of the feeder as depicted in Figure 2. Besides, an active filter is installed at the end of the feeder line. The active filter should act like impedance characteristic [10]. This is due to the elimination of whack-a-mole phenomenon. The purpose of an active filter is to damp out harmonic propagation throughout the feeder line. The harmonic voltage can be detected by simply compesenting a current injected into the feeder line.

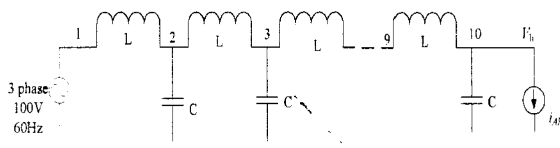


Figure 2: Distribution line feeder with lumped parameters

Practically, the ideal situation has to be considered to determine best location of inverter current sources. Set combination of fundamental, third, fifth and seventh frequency harmonics applied continuously into the distribution line feeder. It is connected in parallel with the capacitance in the line feeder as shown in

978-0-7695-3648-4/09 $25.00 © 2009 IEEE
DOI 10.1109/AMS.2009.127

IEEE computer society

Figure 3. The parameter is base on ideal value of inverter that connected into the grid system. It used same characteristic of inverter with different effect of frequency. The parameter used can be illustrated in Table 1.

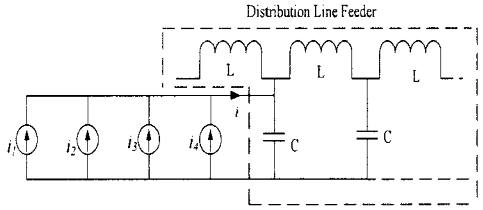


Figure 3: Combination of inverter current with different frequency harmonics

Table 1: Parameter of inverter current source

	Frequency f (Hz)	Current inverter i (A)
i_1	60	8
i_2	180	0.1
i_3	300	0.12
i_4	420	0.13

2. Frequency, wavelength and feeder length

The relationship between frequency, wavelength and feeder length would effect the location of active filter installation [9]. Generally, the relationship can be illustrated using the following equation.

$$\lambda = \frac{1}{f\sqrt{LC}} \qquad (1)$$

where λ represents the wavelength and f represents frequency.

As the installation of active filter is on $\gamma < \lambda/4$ at end of the bus feeder, the most effective harmonics damping would exists (note that γ represents the feeder length of the distribution line feeder). However, this is acceptable respectively with the position of harmonic voltage or current source. Whilst, for $\gamma > \lambda/4$ as an active filter represents as an impedance characteristic, the whack-a-mole would be eliminated throughout the feeder. This would correspond to the so-called 'termination' in transmission line theory [10]. Thus, the harmonics current source should be existed at distance $\lambda/4$ from end bus (γ-γ_1 = $\lambda/4$). Hence, the highest value of harmonic voltage appeared at $\lambda/4$ from bus 1. As state in Wada et al [9], the installation of the inverter current source can be determined using this equation.

$$\gamma - \gamma_1 = \frac{\lambda}{4} \qquad (2)$$

where γ is the total length of the feeder and γ_1 is the length of feeder line that should allocate the inverter current source.

3. Total Distortion Harmonics (THD)

THD signal is the measurement of harmonic distortion. It is the ratio between total harmonic components with fundamental frequency, which usually state in percentage value [11].

$$THD = \frac{\sqrt{(h_2)^2 + (h_3)^2 + ... + (h_n)^2}}{h_1} x100\% \qquad (3)$$

where h_2, h_3,..., h_n represent the n[th] harmonic distortions and h_1 is the fundamental harmonic.

4. Experiment Result

4.1 Single-source Inverter

The experimental and simulation using Wada et al [9] model had been done. Throughout the model, the analyses due to best location of inverter current source were studied. All possible locations were tested. From the analysis, the suitable location of inverter current source should be existed at least $\lambda/4$ from end bus (γ-γ_1 = $\lambda/4$). This is caused by the relationship between wavelength, frequency and feeder length. Besides, it is due to mitigation of whack-a-mole effects [9], [10]. This can be proved using the equation (2).

As state in Wada et al [9], the best location of inverter current source should be at least $\lambda/4$ from end bus (γ-γ_1 = $\lambda/4$). For example, let say the location of inverter current source at fifth harmonic want to be determine. From equation (1), value of λ at fifth harmonic frequency would give 18.35 km. As the total length of feeder line tested is 10 km long. Thus, from equation (2),

$$10 - l_x = \frac{18.35}{4}$$

$$l_x = 10 - 4.59 = 5.41 \approx 6km$$

Hence, the possible location of the installation of inverter current source should be at 6 km of the bus, which is at bus 6.

Figure 4 show simulation of voltage-magnifying factor when an inverter current source installed at bus 6 and bus 2. The graph used Kv=1/z as its reference data. This means that it just directly connected with an active filter at end of the bus without any additional inverter current source inject at the distribution line feeder. The harmonic voltage appeared would be approximately equal to bus 1. Thus, it can mitigate a whack-a-mole phenomenon. The comparison between the reference data (Kv=1/z) and inverter current source installed either at bus 6 or at bus 2 were done. As the inverter current source injected into bus 2, the highest harmonic voltage appears at bus 3. This would give slightly different simulation data compare to the references (Kv=1/z). The fifth-harmonic voltage at bus 3 magnify by 1.1 than bus 1. However, the harmonic voltage would equal to bus 1 at the end of bus.

As the inverter injected into bus 6, higher harmonic voltage appears at bus 5. Besides, an equal harmonic voltage of bus 1 would appear at the end of bus. It is quite similar to the reference result simulation. Thus, it implies that installation of inverter at distance of $\lambda/4$ from the end bus would mitigate the whack-a-mole phenomenon.

Figure 5 shows the effect of harmonic current as inverter injected into bus 6. The lowest harmonic current appears at bus 5. This is inversely proportional with the harmonic voltage result. Thus, an impedance characteristic is proved due to Ohm's law.

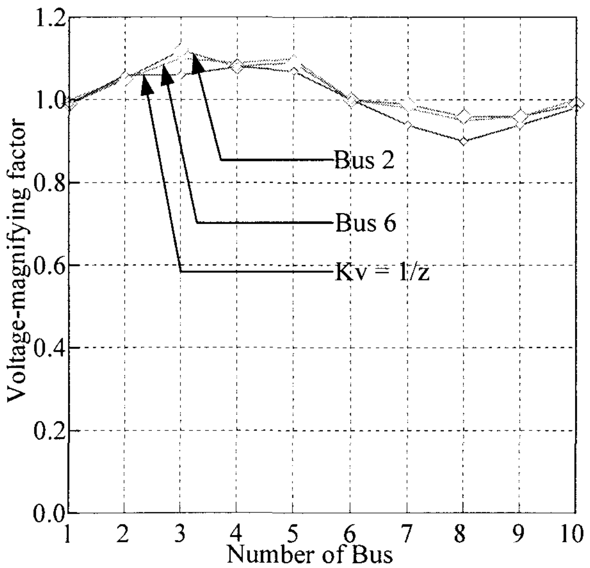


Figure 4: Effect of fifth harmonic voltage

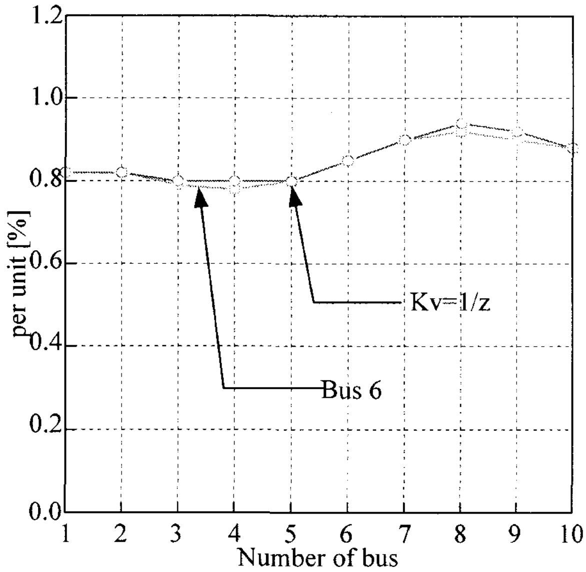


Figure 5: Effect of fifth harmonic current

The possible location for seventh harmonic can be determined. However, the length of the feeder line had to be adjusted. λ for seventh harmonic is 13.1 km which would give $\lambda/4$ as 3.38 km. Thus, the length of the feeder can be adjusted to 7 km and the possible location for inverter is injected at bus 4. As the inverter injected into bus 4, higher harmonic voltage appears at bus 3. Besides, an equal harmonic voltage of bus 1 would appear at end of bus. Thus, it implies that installation of inverter at distance of $\lambda/4$ from the end bus would mitigate the whack-a-mole phenomenon. This can be seen in Figure 6.

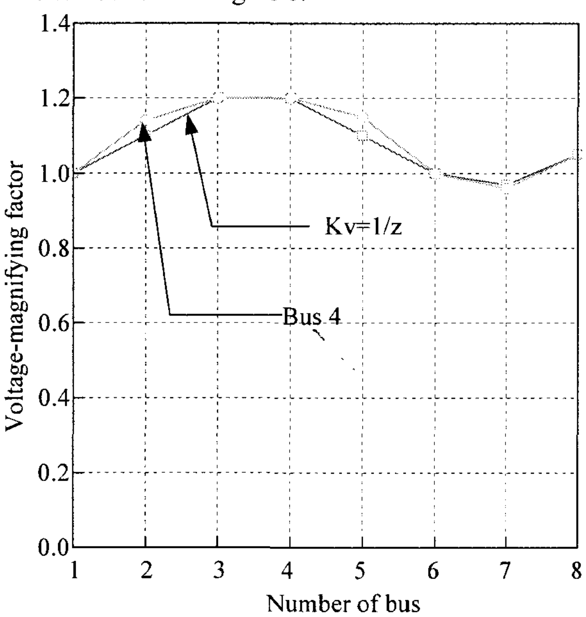
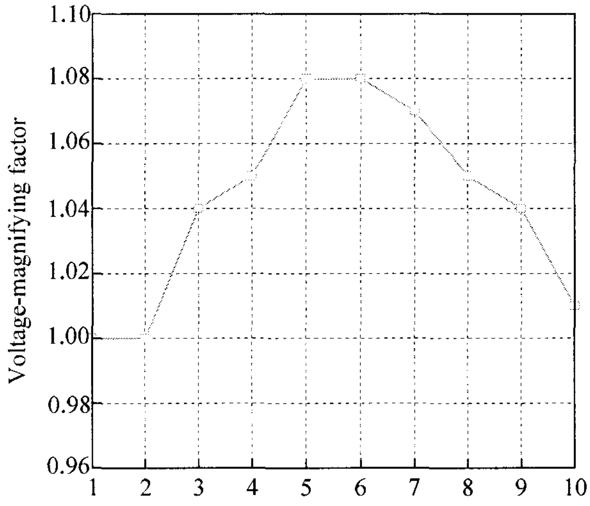


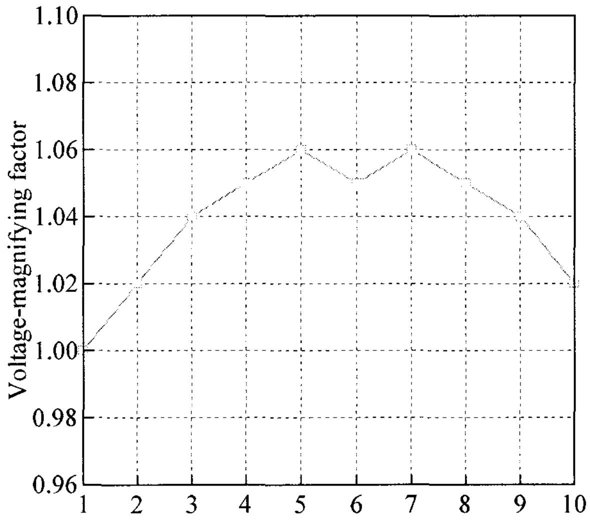
Figure 6: Effect of seventh harmonic voltage.

4.2 Multiple-Source Inverter

Figure 7(a) shows the effect of harmonic voltage as set combinations of frequency harmonic were installed at bus 2. In this case, the harmonic voltage effect would be higher at bus 5 and bus 6. The harmonic voltage is approximately equal to bus 1 at the end of bus. Thus, the whack-a-mole phenomenon is occurred. Whilst, the highest harmonic voltage appeared at bus 5 as combination of frequencies harmonic installed at bus 6 as shown in Figure 7(b). The harmonic voltage is approximately equal to bus 1 at end of bus. Thus, the whack-a-mole phenomenon is mitigated. This proves that the most suitable location for harmonic current source is at distance of $\lambda/4$ from end bus.



(a): Harmonic voltage at bus 2



(b): Harmonic voltage at bus 6

Figure 7: Effect of harmonic voltage

4.3 THD performance of Multiple-source Inverter

Figure 8 show the THD effect as combination of harmonic current source is injected at bus 6. It shows that it would give lower THD performance at bus 5. Thus, it would identical with the mitigated the whack-a-mole phenomenon. Besides, it proved that the location of inverter should be $\lambda/4$ from end bus.

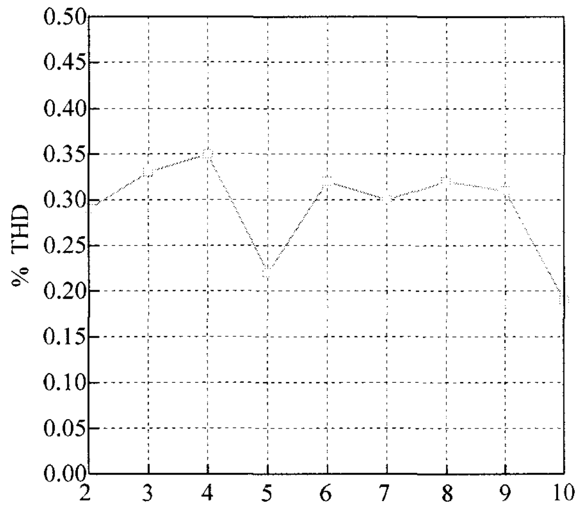


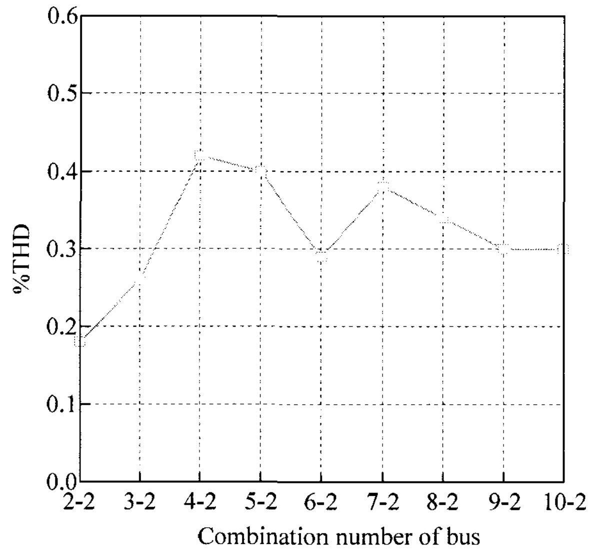
Figure 8: Effect of THD performance

Figure 9 shows the effect as two set combination of harmonic current injected into the feeder line. It shows that the sinusoidal wave of graph trend would appear as the both similar set of harmonic current source applied to the feeder line. From the analysis, there would be several possible location of combination inverter can be installed into the feeder. The location of inverter should give lower THD performance. Thus, effectively to mitigated fifth and seventh harmonics. Besides, the whack-a-mole phenomenon would also be mitigated. There would be three possible effective locations to install the harmonics current source. The location would be at bus 6 and bus 2, bus 8 and bus 3, and also bus 6 and bus 10. Thus, it is proven that the harmonic current source should be located at $\lambda/4$ or $\lambda/2$ from end bus. It would give lower THD performance and mitigated fifth and seventh harmonics.

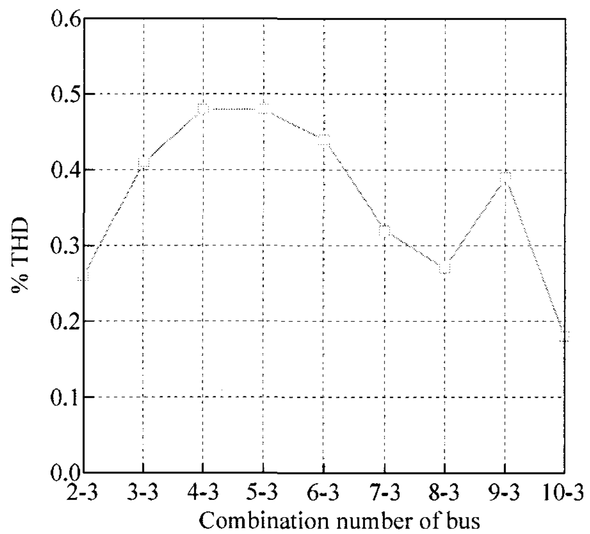
Table 2 shows the THD value for these combinations of harmonic current source due to its harmonics.

Table 2: THD data performance

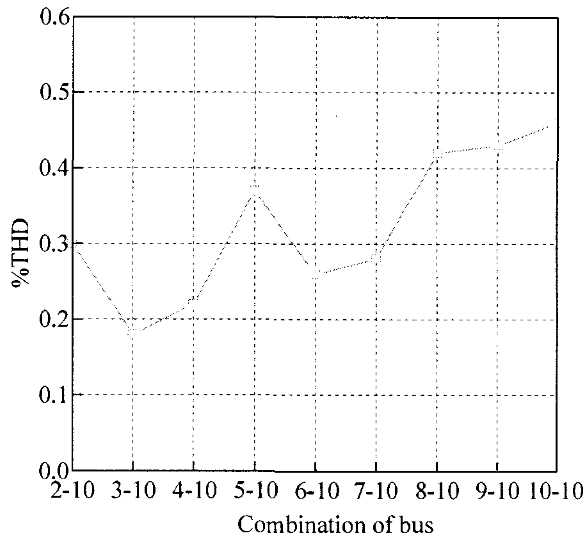
Combination of inverter	THD (%)	180 Hz (h3)	300 Hz (h5)	420 Hz (h7)
Bus 6-2	0.29	0.12 %	0.19 %	0.18 %
Bus 8-3	0.27	0.17 %	0.19 %	0.10 %
Bus 6-10	0.26	0.21%	0.15%	0.05%



(a) Combination with bus 2



(b) Combination with bus 3



(c) Combination with bus 10

Figure 9: The effect of THD performance

5.0 Conclusion

This paper has described the suitable location of inverter current source in feeder line. It used the lump-circuit with per-kilometer parameter as a model for the simulation. From the analysis, the suitable location of inverter installation should be existed at least $\lambda/4$ or $\lambda/2$ from end bus. Thus, the suitable location of inverter installation for fifth harmonics should be at bus 6. Besides, as ideal situation is applied, the best location of inverter installation is still at bus 6 for fifth harmonics effects. While, for seventh harmonic is at bus 4 with length of feeder is 7 km. Thus, the whack-a-mole phenomenon can be mitigated. Besides, there would be several combination of set harmonic current source that can be injected into the feeder. The combination of bus can be either at bus 6 and bus 2, bus 8 and bus 3, or bus 6 and bus 10. All these combination would give lower THD performance and also the fifth and seventh harmonics. From this analysis, it proved that the suitable location of inverter installation existed at least $\lambda/4$. or $\lambda/2$ from end bus. This is due to mitigation of whack-a-mole phenomenon as well as its fifth and seventh harmonics.

6. Acknowledgement

This work is part of the research project for Master of Science in Power Distribution at University of Newcastle. The principle author is a faculty member of

Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM).

7. References

[1] Daly and Morrison (2001) "Understanding the Potential Benefits of Distributed Generation on Power Delivery Systems" Rural Electric Power Conference, 2001. USA: Little Rock, AR.

[2] Slootweg and Kling (2002) "Impact of Distributed Generation on Power System Transient Stability", Volume 2, pp 862-867.

[3] Wang and Nehrir (2004) "Analytical Approaches for Optimal Placement of Distributed Generation Sources in Power Systems", IEEE Transaction on Power System, Volume 19, No. 4, November 2004.

[4] Iyer, Ghosh and Joshi (2006) "Power Flow Control in a Distribution System through an Inverter Interfaced Distributed Generator", Power Engineering Society General Meeting, 2006, IEEE.

[5] Zoka, Sasaki, YoMo, Kawahara and Liu (2004) "An Interaction Problem of Distributed Generators Installed in a MicroGrid" Volume 2, pp 795-799.

[6] Silvestri and Berizzi (1999) "Distributed generation planning using genetic algorithms", Electric Power Engineering, 1999, Power Tech Budapest 99 International Conference. Hungrary: Budapest.

[7] Alvarado F.L (2001) "Location Aspects of Distributed Generation" Volume 1, pp 140.

[8] Coles R. L (2001) "Distributed Generation Can Provide an Appropriate Customer Price Response to Help Fix Wholesale Price Volatility", IEEE Power Engineering Society 2001 Winter Meeting, Colombus, Ohio.

[9] Wada, Fujita and Akagi (2002) "Consideration of a Shunt Active Filter Based on Voltage Detection for Installation on a Long Distribution Feeder", Volume 38, No. 4, pp 1123-1130.

[10] Ackermann, Anderson, Sader and Lennart (2001)" Distribution Generation: A Defination", Electric Power System Research 57, pp 195-204.

[11] Ackermann, Andersson and Soder (2000) "Electricity Market Regulations and their Impact on Distributed Generation", Electric Utility Deregulation and Restructuring and Power Technology 2000, Proceeding, DRPT 2000, International Conference. UK: London.