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Power quality assessment of the interconnection of a microgrid to a local distribution system using real-time simulation

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Abstract
This article evaluates the impact of the interconnection of a microgrid to a local distribution system on power quality. A real-time simulation was used to carry out the study, applying national and international power quality standards, IEEE 1547 of 2018, IEEE 519 of 2014 and NTC 5001 of 2008. Phenomena of voltage harmonics, current harmonics, flicker and DC injection were evaluated on a microgrid case study. The results show that the interconnection of the microgrid produces a high impact on the current harmonics and the DC injection of the local distribution system, while the flicker phenomena and voltage harmonics have a lower impact.

Keywords: Power Quality (PQ); microgrid; real-time simulation; harmonics; flicker; DC injection.

Evaluación de calidad de potencia de la interconexión de una micro red a un sistema de distribución local utilizando simulación en tiempo real

Resumen
Este artículo evalúa el impacto en la calidad de la potencia eléctrica producido por la interconexión de una micro red a un sistema de transmisión, se utilizó la simulación en tiempo real como herramienta para llevar a cabo el estudio y se aplicaron las normas nacionales e internacionales de calidad de potencia IEEE 1547 de 2018, IEEE 519 de 2014 y la NTC 5001 de 2008. Los fenómenos de armónicos de voltaje, armónicos de corriente, flicker e inyección DC son evaluados sobre una micro red caso de estudio. Los resultados muestran que la interconexión de la micro red produce un alto impacto en los armónicos de corriente y la inyección DC del sistema de transmisión regional, mientras que, los fenómenos de flicker y armónicos de voltaje tuvieron un menor impacto.

Palabras clave: calidad de potencia; micro red; Simulación en Tiempo Real (SimTR); armónicos; parpadeo; inyección DC.

1. Introduction

Microgrid is the electrical network of the future on small scale and has attracted more and more attentions of power researchers and companies, as it offers three key benefits: 1) It increases energy efficiency through the use of distributed energy resources, 2) It reduces the carbon footprints in the production of electrical energy and 3) It improves the reliability of electricity delivered to end-uses [1,2].

At the global level and through the Paris Agreement, 195 countries committed themselves to reduce the emission of greenhouse gas emissions, where an important means to meet with the objective of the Agreement is to start covering the energy demand by Microgrids, using renewable energies, [3].

Despite its benefits, the implementation of microgrids create a new challenge in maintaining the power quality of the network and in meeting the limits required by the standards [4]. The problems of power quality in microgrids

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are more severe than those in traditional networks due to the natural intermittency of their distributed energy resources (DERs) and the increased use of power electronic converters, [3,5].

The purpose of this article was to evaluate the impact of the utility grid on power quality when a microgrid is interconnected to a local distribution system, applying the national and international power quality standards IEEE Std 1547 of 2018, IEEE Std 519 of 2014 and NTC 5001 of 2008 [6-8].

This study was carried out using Real-Time Simulation. First, a microgrid model was selected as a case study, then the selected model was simulated in a real-time laboratory, and finally the data were exported to MATLAB, where a detailed analysis was performed.

In the context of this article, a microgrid comprises a MV (≈1–69 kV) locally-controlled cluster of DERs, including storage systems, that from the grid's perspective behaves as a single producer or load both electrically and in energy markets, [2].

Section 2 provides an overview of the phenomena and their effects on power quality produced by the interconnection of a microgrid, according to the regulations. Section 3 presents the microgrid selected as a case study. Section 4 depicts the simulation scenarios and results and section 5 discusses the power quality results and assesses the impact and effects of the interconnection of the microgrid to a local distribution system.

2. Power quality mechanism caused by interconnection

According to [3,9,10], the interconnection of a microgrid to the electrical distribution system can affect the waveform of voltage and current. Hence it is necessary to comply with the power quality parameters, in order to ensure a safe interconnection.

The IEEE Std 1547-2018 establishes criteria and requirements for interconnection of DERs with electric power systems. For power quality requirements, the standard provides the limitations of the phenomena, DC injection, flicker and harmonics, [6].

These phenomena were evaluated at a point of common coupling (PCC) in the microgrid case study, as required by the standard. Below each phenomenon and how it was evaluated are explained.

2.1. *Harmonics measurement*

The measurement of harmonics is performed in accordance with IEEE Std 1547-2018 and its referred standard IEEE Std 519-2014. The harmonics phenomenon was evaluated for voltage and current and the THD and TRD indexes were used, respectively. The eq. (1)-(2) show the expression to calculate these indices.

$$THD_{\mathrm{v}} = \frac{\sqrt{\sum_{h>1}^{50} {V_h}^2}}{V_1} \times 100\% \quad (1)$$

$$TRD = \frac{\sqrt{{I_{rms}}^2 - {I_1}^2}}{I_{rated}} \times 100\% \quad (2)$$

2.2. *DC injection measurement*

The DC injection was measured in accordance with the IEEE Std 1547-2018 and its extended serie the IEEE Std 1547.1-2005, [11]. The DC injection index is calculated by eq. (3).

$$I_{DC} = \frac{I_0}{I_{rated}} \times 100\% \quad (3)$$

2.3. *Flicker measurement*

The flicker measurement was performed in accordance with IEC-61000-4-15. The index used for the flicker measurement was the Epst, which is calculated by eq. (4).

$$E_{pst} = (0{,}0314P_{0{,}1s} + 0{,}0525P_{1s} + 0{,}0657P_{3s} + 0{,}28P_{10s} + 0{,}08P_{50s})^{1/2} \quad (4)$$

The eq. (1) - (4) were implemented in Matlab and they were calculated for multiple scenarios of the microgrid case study.

3. Microgrid selected as a case study

Fig. 1 presents the microgrid selected as a case study.

The microgrid was developed by the Canadian company OPAL-RT Technologies and was published in 2015 in the International Conference on Sustainable Mobility Applications, [12].

- **Wind generation:** a wind turbine delivering a maximum power of 10 kW at a wind speed of 15 m/s.
- **Solar Generation:** includes a type SunPower solar panel, delivering a maximum power of 5 kW at 1000 W/m^2 irradiance. The PV film is connected to the grid through a 2-level IGBT inverter.

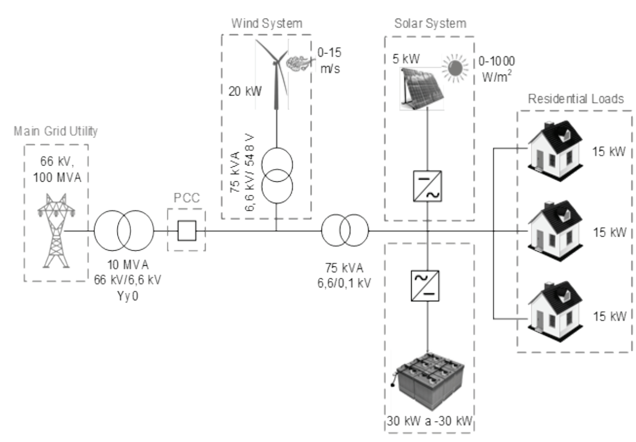

Figure 1. Microgrid case study
Source: The Authors.

- **Storage system:** a lead-acid battery connected to the grid via a 2-level IGBT inverter. The purpose of the battery is to absorb or deliver the difference between the power generated by the renewable sources and the total load power.
- **Residential loads:** Three R-L loads representing a neighborhood.

The microgrid is connected to a large distribution network and includes:

4. Simulation scenarios and results

The microgrid is a complex electrical network which creates big technological challenges for its simulation, due to the number of parameters and components to be introduced. Unpredictable climate changes, the parameters of renewable energy resources, the power electronics, the control system and communications are key factors that make microgrid essential for the use of non-traditional simulations.

Real-Time Simulation is a solution that allows studying these systems by simulating the effects of multiple scenarios under risk free conditions close to reality, prior to their implementation in the field. The microgrid case study presented in Fig. 1 is simulated in real time, using the Real-Time laboratory of the company PTI S.A. For the development of this simulation, the OP5600 simulator and the RT-LAB software were used, [13,14].

Five scenarios were simulated in the microgrid case study. The scenarios show the behavior of the microgrid on a typical day, recreating high, medium and low load demand values. In addition, a zero scenario was simulated, which corresponds to the utility network operating prior to the interconnection of the Microgrid to calculate the power quality reference values of the utility.

Table 1 presents the 5 simulated microgrid scenarios, including scenario 0 that corresponds to the microgrid disconnected from the electrical distribution system. For scenarios 1 to 5 the battery was 100%.

Table 1.
Microgrid scenarios simulated

Scenario	Load (kW)	Psolar (kW)	Pwind (kW)	Pbat (kW)	Putility (kW)
0	0,0	0,0	0,0	0,0	0,0
1	15	-0,06	7,92	7,10	0,0
2	30	4,7	7,55	18,0	0,1
3	45	-0,07	20,6	24,0	-0,1
4	10	5,0	0,0	4,9	0,0
5	30	0,0	20,6	9,6	0,2

Source: The Authors.

Table 2.
Simulation scenarios results.

Scenarios	THD (%)	TRD (%)	Flicker	Inyección DC (%)
0	0,07	0,08	0,014	0,08%
1	0,11 ✔	0,90 ✔	0,04 ✔	0,33% ✔
2	0,11 ✔	1,46 ✔	0,05 ✔	0,34% ✔
3	0,11 ✔	2,43 ✔	0,05 ✔	0,31% ✔
4	0,11 ✔	1,07 ✔	0,04 ✔	0,37% ✔
5	0,11 ✔	0,88 ✔	0,04 ✔	0,26% ✔
Objectives IEEE 1547	5%	5%	0,35	0,5%

Source: The Authors.

Once the real-time simulation was carried out, the data for each scenario were exported to Matlab where a detailed analysis was performed, the power quality parameters mentioned in section 2 were calculated. Table 2 shows the results obtained from the Real-time simulation.

Another requirement of the IEEE Std 1547-2018 is to comply with the limits of individual harmonic distortion for the current. Fig. 2 depicts a graph showing the individual harmonic distortions of current as a percentage of the rated current. The graph also shows that each harmonic component satisfies the standard.

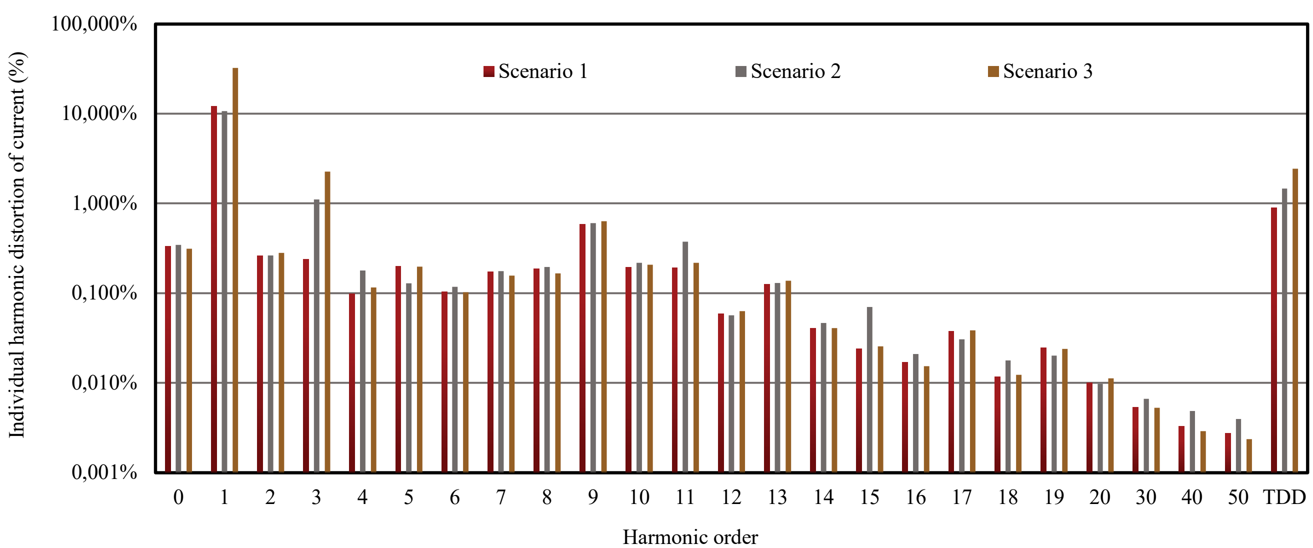

Figure 2. Individual harmonic distortion of current for three scenarios
Source: The Authors.

5. Analysis of results

All the phenomena evaluated in the microgrid case study comply with standard requirements. This is due to the design of the microgrid, since it has multiple elements such as third-order filters, link capacitors, and fast control actions for inverters, which help maintain an adequate service of electric power. In this section, the results of each of the power quality phenomenon are discussed.

5.1. Harmonic measurement results

According to [15–18], the presence of harmonics is one of the most important phenomena in the study of power quality and its evaluation is essential for the interconnection of new non-conventional energy sources. The findings are discussed in terms of the harmonics phenomenon.

5.1.1. Harmonic voltage results

Voltage harmonics had a low impact on the interconnection of the microgrid to the distribution system. Its index THD did not vary considerably and remained constant in comparison with the different simulated microgrid scenarios, thus complying with standard limit requirements. The findings also show that the interconnection of the microgrid does not produce significant voltage harmonic contamination.

5.1.2. Harmonic current results

The current harmonics, measured by the TRD index, had a high impact on the interconnection of the microgrid, since its value increased significantly. From the results, it is clear that the TRD varies according to the power delivered by the renewable energy sources and the storage system.

On the other hand, compliance of harmonics with standard regulations does not necessarily mean that it is not a source of concern for microgrids. The fact that its value increases along with the penetration of renewable energies and the battery bank, adds to other findings from other studies [17,18].

The results indicate that the phenomenon of current harmonics will be more severe with the increase of the penetration of unconventional energy sources, which should be paid more attention for future studies.

Finally, and based on Fig. 2, the results indicate that the third and ninth harmonics are relatively large respect to the fundamental. Therefore, if necessary, the first step to reduce the harmonic content of the signal would be to install an appropriate filter.

5.2. Flicker measurement results

The flicker phenomenon has a medium impact on the interconnection of the microgrid. The results obtained, which were measured by using the Pst index, comply with the IEEE Std 1547 of 2018 and indicate that the microgrid case study does not present any problem derived from this phenomenon. Therefore, its value did not vary considerably because of the interconnection of the microgrid and remained unchanged in the different simulated scenarios.

5.3. DC injection measurement results

The phenomenon of DC injection had a high impact on the interconnection of the microgrid, as its value increased considerably. The results complied with the IEEE Std 1547 standard of 2018 and did not present important variations in the different scenarios; however, its values were close to the limit required by the standard, a finding to be considered in future studies.

6. Impact produced on power quality by the microgrid interconnection

Current harmonics poses one of the main problems in power quality when using microgrids and the integration of renewable energy sources. Our findings are supported by [16,18,19] and guide IEEE 1547.2-2008 [20]. In [18], it was found that the third current harmonic is relatively high and, as such, special attention should be paid to it. Additionally, it was found that current harmonics and the TRD index increase with the penetration level of renewable sources, as shown in the first 3 scenarios.

The DC injection phenomenon shows a high impact due to the interconnection of the microgrid. However, the literature, reveals that this phenomenon is not studied as frequently as is current harmonics. Therefore, future power quality studies should have this as one of their aims.

The microgrid design in this case study guarantees good functioning of the network leading to compliance with the power quality limits required by standard regulations. This is because microgrid incorporates multiple elements such as a third-order filter in the photovoltaic system and battery bank, link capacitors, and quick control actions for inverters, which help maintain an adequate supply of electric power.

Table 3 summarizes the most relevant phenomena and the effects of microgrid interconnection on power quality

Table 3.
Main effects produced by the microgrid interconnection.

Phenomenon	Impact*	Effects on the electrical grid
Current harmonics	High	Temperature Transformers increment, which overheats the neutral conductor. The above can cause an erroneous trip for overcurrent. Insulation life decrement.
Voltage harmonics	Low	No important effect
Flicker	Medium	Can cause remarkable fluctuation on luminic loads
DC injection	High	Distribution transformer saturation that creates an objectionable harmonic source

Source: The Authors.
* A qualitative indicator resulting from the increase of the indexes due to the microgrid interconnection.

The greatest impacts of the microgrid interconnection are the current harmonics and the DC injection. The severity of the harmonic pollution depends on the power electronic converter technology, its filtering, and its interconnection configuration. According to [20], there is concern about the contribution. However, the problem has been reduced because the new inverters come with solid state technologies that use PWM modulation for their operation. These new inverters can generate a clean output and normally meet the requirements of IEEE Std 1547 of 2018.

Currently, new technologies such as filters and smart inverters are emerging in response to the negative effects generated by the interconnection of renewable energies.

7. Conclusions

This article evaluates the impact of the interconnection of a microgrid to a local distribution system on power quality. Real-time simulation was used as a tool to perform the study, applying national and international standards, NTC 5001 of 2008, IEEE 519 of 2014 and IEEE 1547 of 2018 for power quality.

The interconnection of the microgrid to the local distribution system had a high impact on current harmonics. Index TDD showed important variations produced by different levels of penetration of renewable sources and the battery bank. However, the phenomenon always complied with the objectives established by the regulations.

The third and ninth current harmonics are relatively large, so they must be considered for the possibility of installing of filter.

The interconnection of the microgrid had a low impact on the voltage harmonics. Index THD remained constant when comparing the different simulated scenarios and met the limits required by current regulations.

The interconnection of the microgrid had a high impact on the phenomenon of DC injection, (0.37%), and was close to the limit required by the norm (0.5%). It is suggested that this phenomenon be paid special attention in future studies of power quality.

The interconnection of the microgrid had a medium impact on the flicker phenomenon. Its results meet the requirements of the IEEE Std 1453 standard of 2015 and does not pose a special concern for any scenario.

Because of the complexity of a microgrid, real-time simulation is a solution that allows carrying out studies of multiple scenarios under conditions close to reality.

In real-time simulation, a substantial amount of time is saved, compared to off-line simulation. In our study, off-line simulation took 4 hours, while real-time simulation took1 minute.

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References

[1] Li, D. and Zhu, Z.Q., A novel integrated power quality controller for microgrid. IEEE Transactions on Industrial Electronics, 62(5), pp. 2848-2858, 2015. DOI: 10.1109/TIE.2014.2362495

[2] Hatziargyriou, N., Asano, H., Iravani, R. and Marnay, C., Microgrids. IEEE Power and Energy Magazine, 5(4), pp. 78-94, 2007. DOI: 10.1109/MPAE.2007.376583

[3] García, C., Vallejo, G., Higgings, M. y Escobar, E., El acuerdo de París. Así actuará Colombia frente al cambio climático. [online]. 1ra Ed. WWF-Colombia, 2016, 52 P. [date of reference August 18th of 2018]. Available at: https://www.wwf.org.co/?266971/El-Acuerdo-de-Pars-As-actuar-Colombia-frente-al-cambio-climtico

[4] Carvajal, M., Gomez-Luna, E. and Marlés-Sáenz, E., Methodology for technical feasibility analysis in the installation of microgrids. Journal of Engineering Science and Technology Review, 12(5), pp. 176-187, 2019. DOI: 10.25103/jestr.125.20

[5] Kumar, D., Zare, F. and Ghosh, A., DC Microgrid technology: system architectures, AC grid interfaces, grounding schemes, power quality, communication networks, applications, and standardizations aspects. IEEE Access, 5, pp. 12230-12256, 2017. DOI: 10.1109/ACCESS.2017.2705914

[6] IEEE Standard for Interconnection and interoperability of distributed energy resources with associated electric power systems interfaces, in: IEEE Std 1547-2018, Revision of IEEE Std 1547-2003, pp.1-138, 2018. DOI: 10.1109/IEEESTD.2018.8332112

[7] Transmission and Distribution Committee. IEEE Recommended practice and requirements for harmonic control in electric power systems, IEEE Std., pp. 519-2014, 2014. DOI: 10.1109/IEEESTD.2014.6826459

[8] Comité Técnico 129 calidad de energía eléctrica. Norma Técnica Colombiana - NTC 5001, Calidad de la potencia eléctrica. Límites y metodología de evaluación en punto de conexión común, 2008.

[9] Xu, L., Miao, Z., Fan, L. and Gurlaskie, G., Unbalance and harmonic mitigation using battery inverters, Proceedings of North American Power Symposium (NAPS), pp. 1-6, 2015. DOI: 10.1109/NAPS.2015.7335119

[10] Vechiu, I., Etxeberria, A. and Tabart, Q., Power quality improvement using an advanced control of a four-leg multilevel converter, Proceedings of IEEE 16th Workshop on Control and Modeling for Power Electronics (COMPEL), pp. 1-6, 2015. DOI: 10.1109/COMPEL.2015.7236486

[11] IEEE Standards Coordinating Committee 21. IEEE Standard conformance test procedures for equipment interconnecting distributed resources with electric power systems, IEEE Std., 1547.1-2005, 2005. DOI: 10.1109/IEEESTD.2005.96289

[12] Yamane, A. and Abourida, S., Real-time simulation of distributed energy systems and microgrids, in: Proceedings of 2015 International Conference on Sustainable Mobility Applications, Renewables and Technology (SMART), pp. 1-6, 2015. DOI: 10.1109/SMART.2015.7399214

[13] Gomez-Luna, E., Candelo, J. and Marlés-Sáenz, E., Current status and future trends in protection, control and communications testing in electrical grids using real-time simulation, Journal of Engineering Science and Technology Review, 11(4), pp. 204-214, 2018. DOI: 10.25103/jestr.114.25

[14] Gomez-Luna, E., Palacios-Bocanegra L. and Candelo, J., Real-time simulation with OPAL-RT technologies and applications for control and protection schemes in electrical networks, Journal of Engineering Science Technology Review, 12(3), pp. 136-144, 2019. DOI:10.25103/jestr.123.19

[15] Ivry, P., Thomas, D. and Sumner, M., Assessment of power quality in a microgrid with power electronic converters, Proceedings of 2016 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), pp. 825-827, 2016. DOI: 10.1109/APEMC.2016.7522879

[16] Seritan, G., Tristiu, I., Ceaki, O. and Boboc, T., Power quality assessment for microgrid scenarios, Proceedings of 2016 International Conference and Exposition on Electrical and Power Engineering (EPE), pp. 723-727, 2016. DOI: 10.1109/ICEPE.2016.7781434

[17] Ruiqi, W., Zhanxin, J., Sun, L., Zhaoxin, W., Wenjuan, J., Yan, C. and Yong, Z., Power quality control strategy of islanding microgrid under distorted and unbalanced conditions, The Open Electrical & Electronic Engineering Journal, 8, pp. 559-566, 2014. DOI: /10.2174/1874129001408010559

[18] Wang, J., Du, X., Li, G. and Yang, G., Harmonic analysis of the interconnection of wind farm, Electronics and Signal Processing, 97, pp. 1031.1038, 2011. DOI: 10.1007/978-3-642-21697-8_131

[19] Kumary, S., Oo, V., Shafiullah, G. and Stojcevski, A., Modelling and power quality analysis of a grid-connected solar PV system, Proceedings of 2014 Australasian Universities Power Engineering Conference (AUPEC), pp. 1-6, 2014. DOI: 10.1109/AUPEC.2014.6966605

[20] IEEE Application Guide for IEEE Std 1547™. IEEE standard for interconnecting distributed resources with electric power systems, IEEE Std, 1547.2-2008, pp. 1-217, 2009. DOI: 10.1109/IEEESTD.2008.4816078

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