International Journal of Engineering & Technology, 7 (3.25) (2018) 492-495

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Improved Control Method to Reduce the Voltage and Current Harmonics in a Microgrid Subjected to Non-linear Load Conditions

Attaullah Khidrani[1,2]*, M.H. Habibuddin[1], Muhammad Paend Bakht[1,3], Aliyu Hamza Sule[1,4], Raza Haider[2]

[1]*Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor, Malaysia*
[2]*Faculty of Electrical Engineering, Baluchistan University of Engineering and Technology, Khuzdar, Pakistan*
[3]*Faculty of Information and communication Technology BUITEMS, Quetta, Pakistan*
[4]*Department of Electrical Engineering, Hassan Usman Katsina Polytechnic, Nigeria*
**Corresponding author E-mail: khidraniatta@gmail.com*

Abstract

For the past few decades, the distributed renewable energy sources (RES) have become the main alternative to centralized power generation system, mainly due to economic and environmental concerns. The two major problems in employing this RES are the severe current harmonic contents in their output current and the imbalance in system voltage and current. Accordingly, this research work presents a method to minimize the current and voltage harmonic contents in a three-phase hybrid photovoltaic (PV) and wind turbine (WT) Grid Connected Inverters (GCI) subjected to nonlinear and unbalanced load conditions. The proposed method effectively offsets the harmonic contents in voltage and current of the system under study without relying on additional equipment, including passive and active filters. The obtained results reveal the effectiveness of proposed control strategy in reducing the total harmonic distortion (THD) while simultaneously correcting any imbalance in the system. The newly developed method, which features the GCI inverters using synchronous reference frame (SRF), proved itself to be very effective, as evident from the simulation results obtained.

Keywords: *photovoltaic (PV); distributed generation (DG); wind turbine (WT) non-linear loads; harmonics; microgrid*

1. Introduction

The structure of the current power system is now changed by the introduction of renewable energy sources (RES). Due to the economic and environmental concerns, the RES has become the main alternative to centralized power generation system. These RES combines together along with the energy storage devices like battery, supercapacitor and flywheel to form a microgrid (MG) which is able to supply the power to the local grid or the utility grid. This recent trend of building MGs by using distributed generators (DGs) and energy storage devices is increasing very rapidly due to its flexibility and free source availability [1]. These DGs are connected to the MG using a non-linear power electronic interface like Voltage Source Inverter (VSI) in order to share the active and reactive powers to main utility grid [2]. However, the inverters based on Pulse Width Modulation (PWM) may cause power quality and control issues. Usually, the voltage and current distortions are caused by non-linear loads in electrical power distribution networks. The dynamic and steady-state behaviour of the VSI based DGs affect the utility grid, which results in severe voltage and current harmonics [3]. The proposed inverter control strategy reduces the switching harmonics and enhances the grid power quality by generating active power.

The problems created by exchanging the energy from direct current (dc) to alternating current (ac) through inverters can be overcome using active power filters (APFs). The APFs provide flexible solutions for voltage and current harmonics suppression [4]. Usually, the APFs used in MGs with interface inverters act as the voltage and current source, once connected to the central grid. The interface inverters must be so designed to deal with the imbalance in utility grid voltage and the voltage harmonics [5], well within the IEEE standard range provided by the waveform quality requirements, at less than 5%. The compensation of voltage distortions is usually mitigated by using series and shunt APFs right at the PCC, mentioned in [3, 6]. However, using APFs results in many major drawbacks, including higher operational costs, large sizes, switching amount, increased convolution in control algorithms, and the need for interface circuits to offset unstable and non-linear loads [7].

In the studies by [8, 9], a number of methods were proposed for the control of DGs as the harmonic compensators for both current and voltage. In studies by [10] and [9], meanwhile, methods to offset harmonics present in the voltage and current in grid-connected MGs were suggested. The proposed current controller technique, comprising a repetitive controller (RC) and a proportional–integral (PI) controller, was designed in the synchronous reference frame (SRF), as explained in a study by [10]. To solve this issue, the paper proposes a replacement of APFs with existing inverter that can be interfaced the RES to the grid and it consists of SRF control scheme for the three-phase grid-connected inverters (GCI). The proposed technique can inject controlled power into the grid, and this can compensate for the voltage and current harmonics. The research focus is to measure the quality of voltage and current at the PCC, in particular, the THD mitigation in the

MG. Moreover, the proposed method can easily be adopted in the DG control system with no additional hardware installation, making it suitable for low budget power controllers. The major contribution of this work is as follows: (i) Replacement of APF to the three-phase GCI and SRF which enables to reduce the harmonics of voltage and current at the DGs; and (ii) Providing voltage control during an unbalanced condition in an MG.

The remaining of the paper is summarized as follows. The proposed control method is discussed in Section 2. The model implementation details are provided in Section 3. Section 4 discusses the simulation results and detailed description. And section 5 gives the conclusion of the paper.

2. Proposed Control Method

The block diagram of the proposed voltage and current control technique for PV and WT grid-connected inverters is shown in Figure 1. The existing control methods are commonly based on the time domain or the frequency domain analyses. To mitigate the harmonics in the system due to the connection of non-linear loads, harmonics of opposite polarity can be injected into the system to correct the distortion in the system sine wave. The SRF control is also known as a *dq* control [11] and is utilized for the GCI control in this research. This technique utilizes a reference frame for *abc* to *dq* transformation module to change it into a reference frame which rotates synchronously, using the grid voltage and the current waveforms transformation. The proposed control approach applied to the interface inverter often involves two sequenced loops, namely, external voltage loop and fast-internal current loop. The voltage loop controls the dc-link, whereas, the current loop normalises the grid current.
The voltage and the current loops are developed to overcome both the power quality and harmonics distortion. Therefore, harmonics offsetting is a vital characteristic of the voltage and current controller. The park transformation is applied for the analysis of the electrical power system, where further transformations were done on the three-phase voltage and current into dq0 coordinates by the matrix [M] as in the following equation:

$$\left[u_d u_q u_0\right] = \left[M\right]\left[U_A U_B U_C\right] \tag{1}$$

$$\left[i_d i_q i_0\right] = \left[M\right]\left[i_A i_B i_C\right] \tag{2}$$

$$\begin{aligned}[M] = \sqrt{\tfrac{2}{3}}[&\sin\alpha \cdot \sin\left(\alpha - \tfrac{2\pi}{3}\right) \cdot \sin\left(\alpha + \tfrac{2\pi}{3}\right) \cdot \alpha \cdot \cos\alpha \\ &\times \cos\left(\alpha - \tfrac{2\pi}{3}\right) \cdot \sin\left(\alpha + \tfrac{2\pi}{3}\right) \cdot \tfrac{1}{\sqrt{2}} \cdot \tfrac{1}{\sqrt{2}} \cdot \tfrac{1}{\sqrt{2}}]\end{aligned} \tag{3}$$

The 3Ø load currents are transformed in dq0 coordinates by [M],

$$\left[i_{Md} i_{Mq} i_{M0}\right] = \left[M\right]\left[i_{MA} i_{MB} i_{MC}\right] \tag{4}$$

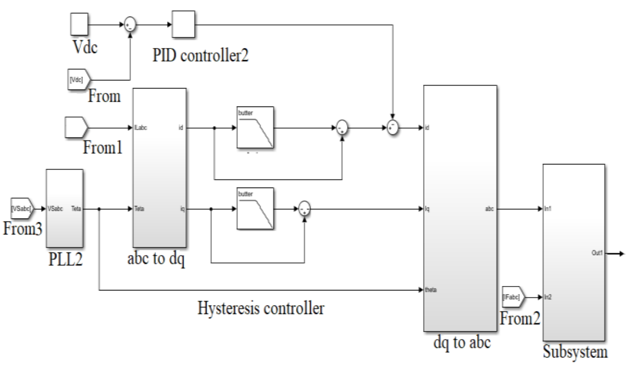


Fig. 1: Block diagram for the newly developed voltage and current controller

Using the average of two currents i.e. i_{MA} and i_{Md} in the domain 0-2π, the elements of i_{MA} and i_{Mq} are obtained as follows:

$$\begin{aligned} i_{Md} &= \frac{1}{2\pi}\int_0^{2\pi} i_{Md}\, d\omega t \\ i_{Mq} &= \frac{1}{2\pi}\int_0^{2\pi} i_{Mq}\, d\omega t \end{aligned} \tag{5}$$

Where,

$$i_{Md} = \sqrt{\frac{2}{3}}\left[i_{MA}\sin\omega t - i_{MB}\sin\left(\omega t - \frac{2\pi}{3}\right) + i_{MC}\sin\left(\omega t + \frac{2\pi}{3}\right)\right] \tag{6}$$

$$i_{Mq} = \sqrt{\frac{2}{3}}\left[i_{MA}\sin\omega t - i_{MB}\sin\left(\omega t - \frac{2\pi}{3}\right) - i_{MC}\sin\left(\omega t + \frac{2\pi}{3}\right)\right] \tag{7}$$

Equations (6) and (7) can be written as

$$a_{A1}^{(i)} = \sqrt{\frac{2}{3} i_d\left(t\right) and\, b_{A1}^{(i)} \sqrt{\frac{2}{3} i_q\left(t\right)}} \tag{8}$$

From the equation (8), the dc elements of i_{Md} and i_{Mq} are the quantities of *iMs* and the controlling/compensating voltage and current harmonics of proposed DGs output waveforms. Now, i_{MS} and i_{FM} are measured in *abc* coordinates.

$$I_{FM} = i_M - i_{MS} \tag{9}$$

3. Scheme Implementation on Microgrid

As for the elementary MG configured in Figure 2, the power system is supposed to be radial with few feeders and a set of loads. The MG contains two DGs consisting of PV and WT, which are connected by the interface inverter to the grid. The WT and PV inverters were subjected to the proposed control method. The load/DGs constraints are enumerated in Table 1. Subsequently, the interface inverter was supplied with a dc voltage, and controlled by the SRF controller.

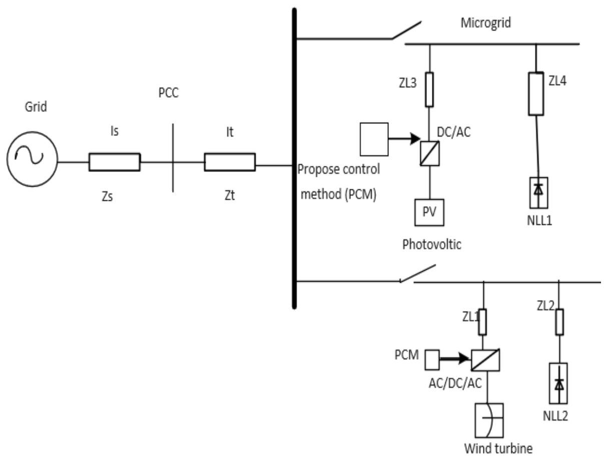


Fig. 2: Proposed architecture of DG

4. Simulation Results and Discussions

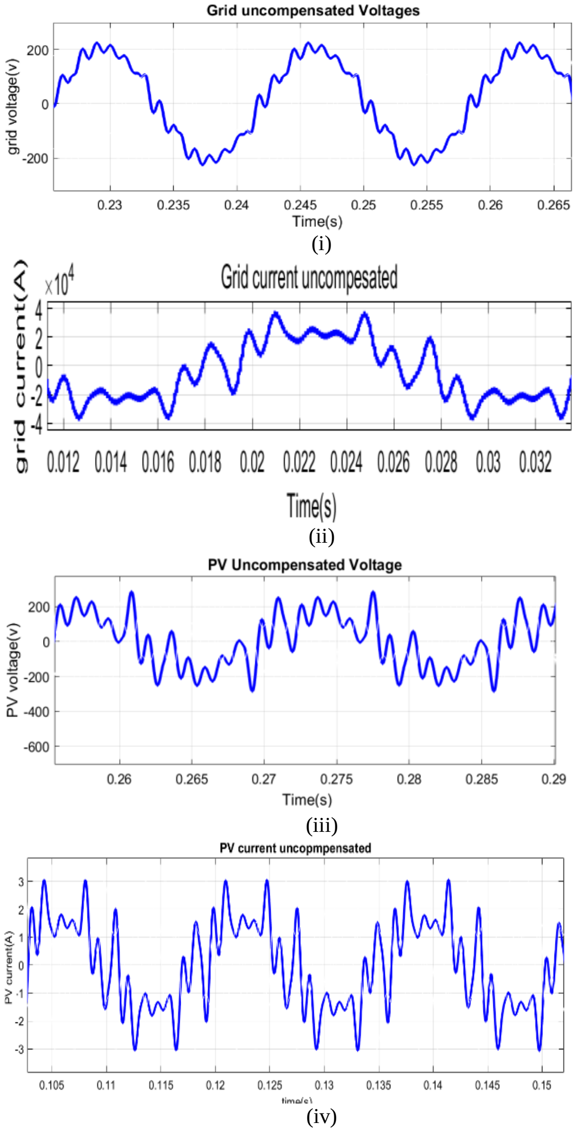
Proposed architecture of DG shown in Figure 2 was simulated in MATLAB/Simulink environment to validate the proposed control strategy for its usefulness, involving two case studies, namely, case-study 1; with harmonic compensation, and case-study 2; without harmonic compensation.

Table 1: Load parameters for the DG units

Type of DG	System Constraints	Values
PV	Inverter switching frequency	10 kHz
	RLC line filter parameters	R=1.55 Ω, L=5e-3 H
	DC-link capacitance	50 µF
	Inverter resistance	5 Ω
	Inverter capacitance	5 µF
	DC-link voltage	545 V
	DG Power	100 kW
WT	Inverter resistance	0.02 Ω
	DC-link voltage	720 V
Rating of non-linear load 1	RL 30 kW, 10 kVAR	12 A
Rating of non-linear load 2	Resistor 0.3 Ω	22 A

4.1. Case-Study 1

In this section, we describe results for the scenario where there is no harmonic compensation at the DGs including WT, PV, and the utility grid. The waveforms of the resulting system in this case-study are shown in Figure 3, which do not involve the compensation devices. The voltage and the current in the system became non-linear and unbalanced due to the presence of DG sources and non-linear loads. Tables 2 shows the voltage, current and THD of the proposed system in this case study1 (uncompensated), and the results of the uncompensated waveforms are as follows:



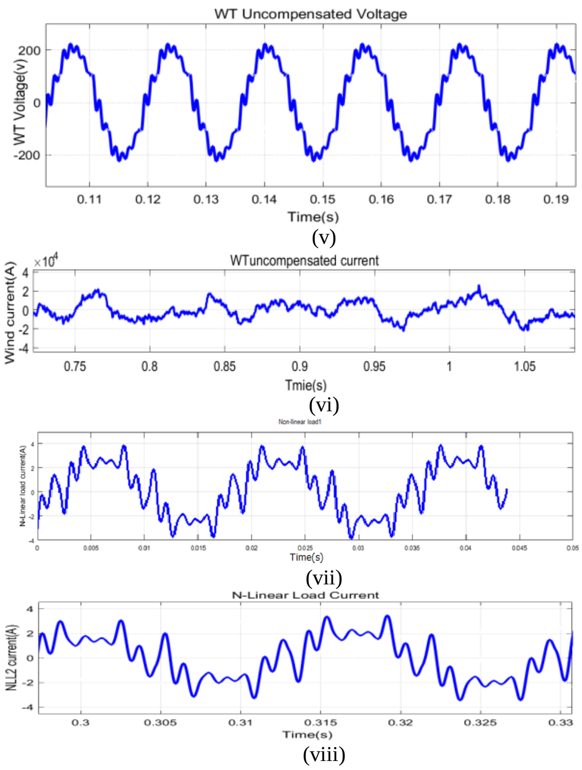


Fig. 3: Grid units and non-linear loads voltage and current waveform without any compensation (i) grid voltage (ii) grid current (iii) PV voltage (iv) PV current (v) WT voltage (vi) WT current (vii) non-linear load1 (viii) Non-linear load 2.

4.2. Case-Study 2

This case study involves an enhanced power quality improvement without the use of such compensation devices as a passive filter and APFs in the MG. The PCC and MG voltage and current compensation are the outcomes obtained from this study. Figure 4 shows the effective values of the harmonic voltage and current compensation for the considered test system. Here, the case-study results prove that the proposed technique was able to compensate the considered system (PCC voltage and current) and DGs, without relying on power compensation devices.

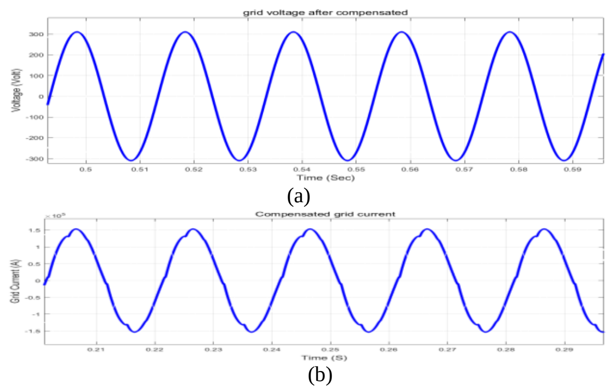


Fig. 4: System Voltage and current waveforms with proposed control method (a) compensated voltage (b) compensated curren

From the results, it is obvious that the THD voltage achieved without compensation was 7.15% and the current obtained was 30.89%, without any compensation, once all the loads and DGs were in connections. The value dropped to 1.87% and 4.02 % simultaneously, using the newly developed control method, lying within the IEEE 519-1992 harmonic standard limits, as displayed in Figure 4. Table 2 shows the voltage, current, and THD values of the studied system for case study-2 (after the implementation of the proposed control technique).

Table 2: THD results of voltage and current

Identifier	Voltage		Current	
	Before compensation	After compensation	Before compensation	After compensation
Main Grid	7.15	1.85	30.89	4.02
PV	7.15	0.69	4.02	4.13
WT	9.59	9.45	4.21	1.93
NL-L1	5.64	-----	-----	-----
NL-L2	20.12	-----	-----	-----

5. Conclusions

This paper presents a new technique to reduce the voltage and current harmonics in MGs by using voltage and current compensation for inverter-based DG units. The scheme comprises an SRF control structure, which is responsible for the control of the power injection into the grid, while simultaneously offsetting the main current harmonics resulting from unbalanced loads. The method can be applied to both three-phase and single-phase systems and is advantageous, in terms of reducing complexity, size and cost of the control strategy, when compared to APFs based methods.

References

[1] D. Stimoniaris, D. Tsiamitros, and E. Dialynas, "Improved energy storage management and PV-active power control infrastructure and strategies for microgrids," *IEEE Transactions on Power Systems*, vol. 31, no. 1, pp. 813-820, 2016.

[2] X. Lu, X. Yu, J. Lai, J. M. Guerrero, and H. Zhou, "Distributed secondary voltage and frequency control for islanded microgrids with uncertain communication links," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 2, pp. 448-460, 2017.

[3] A. Naderipour, A. M. Zin, M. Habibuddin, and J. M. Guerrero, "An advanced current control compensation scheme to improve the microgrid power quality without using dedicated compensation devices," in *Power and Energy (PECon), 2016 IEEE International Conference on*, 2016, pp. 160-165: IEEE.

[4] A. M. Zin, A. Naderipour, M. H. Habibuddin, and J. M. Guerrero, "Harmonic currents compensator GCI at the microgrid," *Electronics Letters*, vol. 52, no. 20, pp. 1714-1715, 2016.

[5] A. Micallef, M. Apap, C. Spiteri-Staines, and J. M. Guerrero, "Mitigation of harmonics in grid-connected and islanded microgrids via virtual admittances and impedances," *IEEE Transactions on Smart Grid*, vol. 8, no. 2, pp. 651-661, 2017.

[6] Q. Liu, Y. Tao, X. Liu, Y. Deng, and X. He, "Voltage unbalance and harmonics compensation for islanded microgrid inverters," *IET Power Electronics*, vol. 7, no. 5, pp. 1055-1063, 2013.

[7] M. Sedighizadeh, M. Esmaili, and A. Eisapour-Moarref, "Voltage and frequency regulation in autonomous microgrids using Hybrid Big Bang-Big Crunch algorithm," *Applied Soft Computing*, vol. 52, pp. 176-189, 2017.

[8] M. Hamzeh, S. Emamian, H. Karimi, and J. Mahseredjian, "Robust control of an islanded microgrid under unbalanced and nonlinear load conditions," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 4, no. 2, pp. 512-520, 2016.

[9] X. Zhang, Q.-C. Zhong, and W.-L. Ming, "Stabilization of a cascaded DC converter system via adding a virtual adaptive parallel impedance to the input of the load converter," *IEEE Transactions on Power Electronics*, vol. 31, no. 3, pp. 1826-1832, 2016.

[10] A. Naderipour, A. M. Zin, M. Habibuddin, M. Moradi, M. Miveh, and H. Afrouzi, "A new compensation control strategy for grid-connected wind turbine and fuel cell inverters in a microgrid," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 8, no. 1, pp. 272-278, 2017.

[11] A. Rygg, M. Molinas, C. Zhang, and X. Cai, "A modified sequence-domain impedance definition and its equivalence to the dq-domain impedance definition for the stability analysis of AC power electronic systems," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 4, no. 4, pp. 1383-1396, 2016.