Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 156 (2019) 396–400

Energy Procedia

www.elsevier.com/locate/procedia

2018 5th International Conference on Power and Energy Systems Engineering, CPESE 2018, 19–21 September 2018, Nagoya, Japan

Power Quality Assessment for AC/DC Hybrid Micro Grid Based on On-Site Measurements

Meng WU[a], Xingyan NIU [b,*], Shiqiao Gao[b] , Junyong WU[a,*]

[a]*Electrical Engineering Department, Beijing Jiaotong University, Beijing, 100044, China*
[b]*R&D China Center, Électricité de France, Beijing, 100005, China*

Abstract

This paper presents the power quality assessment carried out by an experimental analysis of a real AC/DC hybrid micro grid. Voltage variations and the harmonic issues in both AC and DC voltage are analyzed under "on-grid" and "off-grid" mode operation. The results obtained are then compared with the related Chinese national or IEC standard power network compatibility levels. Besides, the equivalent dynamic impedance of battery converter has also been calculated based on the measured data.

Keywords: AC/DC hybrid micro-grid, power quality, harmonic, ripple

1. Introduction

The applications of AC/DC hybrid micro grid has become an obvious trend in power distribution and transmission. It possesses the advantages like decreasing the power loss of AC/DC or DC/AC conversion by the direct power supply to the AC and DC loads, increasing the reliability of network, etc. The power quality analysis is an important issue for the micro grid.

* Corresponding author. Tel.: +8610-56511435 ; +8610-51687107 .
E-mail address: xingyan.niu@edf.fr; wujy@bjtu.edu.cn

10.1016/j.egypro.2018.11.105

In Ref. [1], power quality indexes are analysed in the AC micro grid integrated with a large PV plant through simulation tool and the on-site data.The power quality control and correction of DC micro grid has also been well studied theoretically by Ref. [2]. However, the power quality analysis of AC/DC hybrid micro grid has not been enough addressed or considered comparing to the individual AC or DC micro grid.

In this paper, a detailed power quality assessment for a typical AC/DC hybrid micro grid in Zhejiang province of China based on the real on-site data is reported. The paper is organized as follows: The details of the network configuration and the data acquisition are presented in the 2nd and 3rd section, the 4th section outlines the analysis and the results of the power quality issues. Last section concludes the paper and expresses further level of research work to be achieved in the future.

2. AC/DC hybrid micro grid configuration

The micro grid being considered contains a roof-top photovoltaic power station of 2350 kW, from which 1500 kWp power is connected to the AC bus and 850 kWp is connected to the DC bus. 7 injection molding machines (Haitian MA8000) of 50 kW and the LED lamps of 50 kW are linked as DC loads. Besides, it also contains a lead-carbon battery storage system with rated capacity of 50 kW × 4h, 4 DC electric vehicle charging piles of 60kW, 2 direct-drive wind turbine generators of 5 kW and the corresponding power conversion devices to the network. The configuration of this micro grid network is shown as Fig. 1. The main electronic devices and the system includes:

- Two power quality mitigation instruments (APF): One is connected to the 0.4 kV AC bus, the other is connected to the DC bus.
- Three power flow controllers (PFC): AC/DC converter based on the virtual impedance droop control with a rated power of 250 kVA
- One power electronic transformer (PET): 250 kVA power conversion device transforming 10 kV AC voltage into 560 V DC voltage by using modular multilevel converter (MMC)
- Energy management system (EMS): It's capable of providing the automatic service like seamless connection, real-time monitoring of system status, stability control, operation mode switching, black start, one-button grid connection, etc.

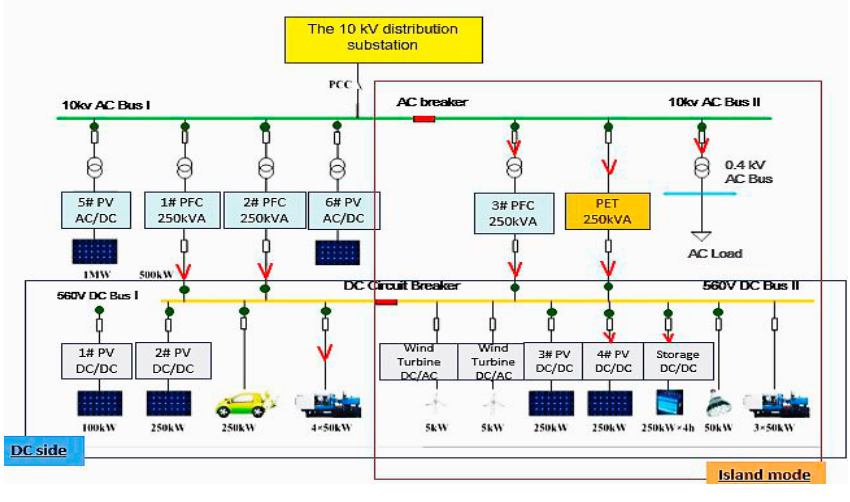


Fig. 1. One example of AC/DC hybrid micro grid network configuration

3. Data acquisition

Data of both AC and DC side under two different operation modes: "on-grid" and "off-grid" have been measured respectively. The sampling frequency is 20 kHz for AC bus voltage and 10 kHz for others, and the total sampling time is 200 seconds. For the AC side, the three phase voltages of AC Bus II, the AC side branch currents of 3#PFC,

PET and AC load have been measured. As to the DC side part, the voltages of DC Bus I and II, together with the output currents of 1#PFC, 2#PFC, 3#PFC, PET, the branch currents of the injection molding loads, 4#PV and the battery have been measured. Under the "on-grid" mode, the active power reference for 1#PFC, 2#PFC, 3#PFC and PET are set to 15 kW, 15kW, 20kW, 20kW. On the "off-grid" mode, the active power reference for 3#PFC and PET are set respectively to 20kW and 0 kW.

The measuring instrument used is the recorder YOKOGAWA DL850E for registering voltage and current waveforms, with the AD conversion resolution setting to 12 bit. The precision of voltage probe is 0.5%, whose range is 0~1000V. And the transformation ratio for the AC voltage is set up to 100:1. The precision of current probe is 1% with a range of -430~430A. The measured branch and the positive direction of those measurements are marked on red arrows as shown in Fig. 1.

4. Power quality description and assessment

Power quality (PQ) issues on AC power system are well studied and all power quality indices are also standardized, however PQ on DC distribution network are just considered by international standardization committees. So there exists a need for studying assessment methods of DC phenomena. A standardized DC power quality indicators may provide with a solid basis of planning and operating of Low Voltage Direct Current (LVDC) system. The emission limits will also affect the allocation and the configuration of the protection system. Adequate power quality levels can guarantee the electrical installations working in a good electromagnetic compatibility environment and enhance their lifetimes [3]. In this section the experimental analysis of both AC and DC power quality issues is carried out according to relative standards in order to quantify the impact level of following issues: DC voltage variation and harmonics.

4.1. DC Voltage variation

Voltage ripple is the residual **periodic** variation of the DC voltage. It can be due to the rectifiers or DC/DC converters controlled by pulse width modulation (PWM) switching or some nonlinear DC loads. Fig. 2 shows an important transient event recorded on the "off-grid" mode operation, in which the ripple waveforms has been measured. The ripple factor γ is defined as the ratio of root square mean (RMS) value of AC component to the DC voltage. In this case $\gamma = \frac{V_{RMS}}{V_{DC}} = \frac{13.5\,V}{571.3V} = 2.4\%$, which is below the acceptable level 5% of an on going technical report of IEC TC8 [3]. Rapid voltage changes （RVC） have also been recorded as the injection molding machines being turned off or down, whose amplitude is 21 V, the ratio is 3.6% and the duration is about 0.3 second. According to the IEC, the definition of RVC is a quick transition in RMS voltage between two steady-state conditions and during which the RMS voltage does not exceed the dip/swell thresolds(10%).

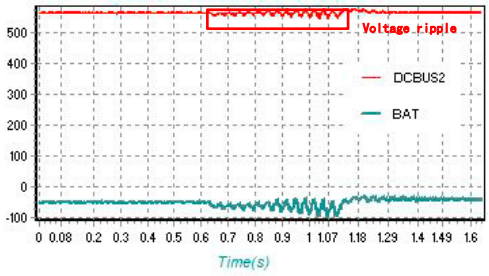


Fig. 2. Transient event waveforms

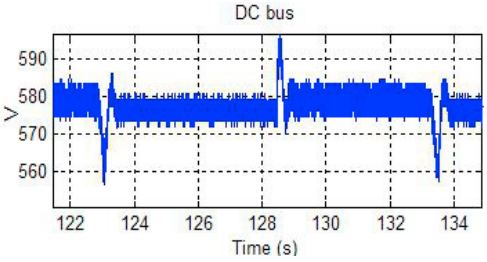


Fig.3. Rapid voltage changes

4.2. Harmonics

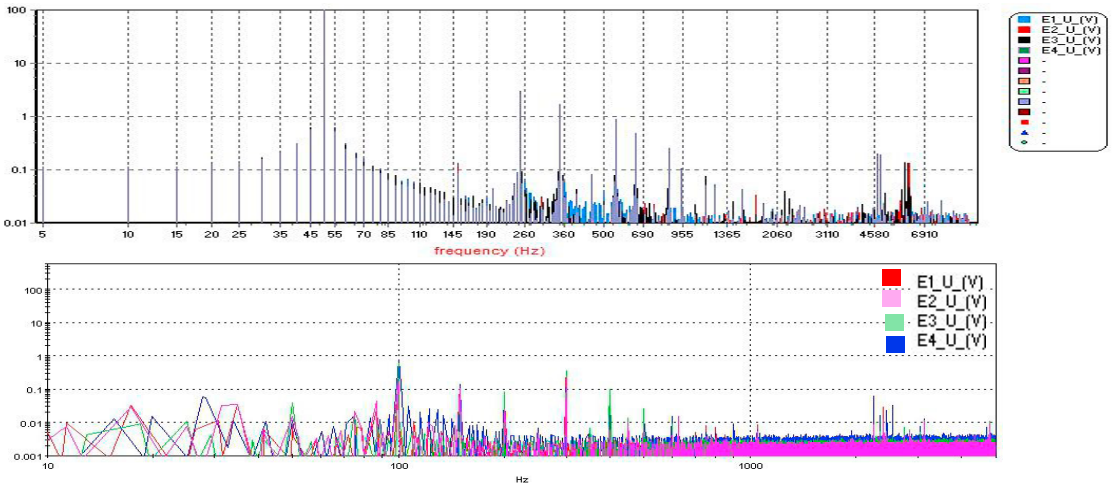
The non-sinusoidal waveforms of voltage or current having frequencies (<2 kHz) other than fundamental frequency are called as harmonics. The main cause of the harmonics are the power electronic devices and the non-linear loads in the power network. Excessive harmonics can cause the following problems to the power network: noises or even information loss generated by the interference with adjacent communication systems, mechanical vibrations of the motors, over-heating of transformers, capacitors and cables, etc. [4].

The equation of Total Harmonic Distortion (THD) of AC and DC voltage are shown respectively in Equ. 1, where V_1 represents the fundamental frequency, V_0 presents the DC component, and h means the harmonic order [5].

$$THD(ac) = \sqrt{\sum_{h=2}^{h=H} \left(\frac{V_h}{V_1}\right)^2},\ THD(dc) = \sqrt{\sum_{h=1}^{h=H} \left(\frac{V_h}{V_0}\right)^2} \tag{1}$$

Only the phase A of 10 kV AC bus voltage is studied. Four measurements from four different scenarios are used for frequency domain computation: “on-grid” operation without APF, “on-grid” operation with APF, “off-grid” operation with APF, “off-grid” operation without APF. They are represented by sources E_1,E_2 E_3 and E_4.

The spectrum diagram is given in Fig. 4. Table 1 describes the Chinese network standard (GB/T14549-93) for harmonics level [6]. From the Fig. 4, it could be drawn that the characteristic harmonic of the PWM converter with the order of (6k±1, k=1, 2, 3…) is the main harmonic frequencies. The maximum odd harmonic ratio appears at 250 Hz with a value of 2.39%, and the maximum even harmonic ratio is 0.04% at 100Hz. So the AC bus voltage power quality confirms with the national standard. There exists some high-frequency disturbances beyond 2 kHz though its level is low: some spectra near 4.8 kHz (about 11V) and near 6 kHz about 8V (only in the cases with APF). Thus it could be drawn that the 6 kHz frequency resulting from the inner APF harmonic pollution. Whereas, there is no compatibility level proposed for these frequencies on MV grid yet.



Statistics values	RMS Values		Max		Min		Mean		THD %	
	DC	AC	DC	AC	DC	AC	DC	AC	DC	AC
E_1U (V)	568.680	5828.029	576.667	8041.998	558.667	-8100.066	568.679	-18.614	0.30	3.41
E_2U (V)	569.440	5835.737	576.667	8087.533	558.667	-8094.289	568.438	-0.002	0.34	3.48
E_3U (V)	564.216	5857.556	569.333	8145.204	560.0	-8144.935	564.215	-3.856	0.29	3.26
E_4U (V)	564.245	5847.727	576.667	8138.605	544.0	-8139.223	564.242	-3.823	0.38	3.48

Fig. 4 spectrum diagram of E_1,E_2 E_3 and E_4 of AC and DC voltage

Over-all voltage quality of the DC voltages is excellent under the 4 operation scenarios. The presence of characteristic and non-characteristic harmonics, inter-harmonics and voltage disturbances above 2 kHz which is mainly caused from the chopping frequencies of converters is recorded. The most important DC ripple is near 100Hz (about 0.75V) in islanding mode where the 50Hz sinusoidal voltages are built by PWM inverters. As PWM chopping frequency is only 2.5 kHz, which is not enough high, there is a little asymmetry on AC voltage waveform.

4.3. Equivalent Dynamic Impedance

In order to identify the equivalent dynamic impedance of power electronic sources, small signal analysis has been carried out from the measured current and voltage in the transient event recorded on the "off-grid" mode operation as shown above in Fig. 2. The dynamic internal impedance is an important factor directly related to the power quality behaviour assessment of static power sources, however it usually cannot be provided by the device manufacturers. By knowing the value of the internal impedance, the evaluation of the impact of the new end-user or new electric installation could be deduced. So the over-all power quality level and margin for further customer connection could be achieved. The result of identification of equivalent dynamic impedance of battery converter from f-domain data processing is presented in Fig. 5. The impedance is about 0.4 Ω from 10 to 100Hz. This value is considerably lower than that deduced from the steady state parameters of battery converter (250kW, 560V). If supposing that the short circuit capacity is 1.25pu, then the equivalent steady state impedance will be 1.0 Ω.

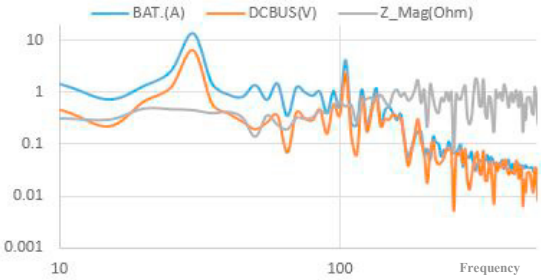


Fig. 5 equivalent dynamic impedance of battery converter

Table1. Harmonic limit of 10kV grid of GB/T14549-9

Rated voltage(kV)	THD (%)	Odd harmonic ratio (%)	Even harmonic ratio (%)
10	4.0	3.2	1.6

5. Conclusions and perspectives

In this study, power quality issues like voltage variation and harmonics are analyzed and quantified in AC/DC hybrid micro grid through an experimental approach. And the important value of the equivalent dynamic inner impedance is also calculated. It has been proved that the power quality of the micro grid studied is good enough to confirm with the Chinese national or IEC standard. Considering the fact that power quality requirements for the DC power have not been completely developed yet, thus results extracted from this study could be used as a guideline to complete the DC power standards. Furthermore, similar to the AC power, the DC voltage also contains AC component of some specific frequencies as given in Fig. 4. So the influence of DC harmonics to the DC load and the mitigation methods will be further researched.

References

[1] Vinayagam, A., Swarna, KSV, Khoo, S.Y. and Stojcevski, A. "Power Quality Analysis in Micro Grid: An Experimental Approach." Journal of Power and Energy Engineering 4 (2016): 17-34.
[2] Gary Chang, HJ LU, etc."On power quality study for a DC micro grid with real-time simulation platform." International Review of Electrical Engineering 6(6) (2011): 2689-2698
[3] IEC TC8-WG9, "Assessment of standard voltages and power quality requirements for LVDC distribution system."
[4] Zhaoan Wang and Jun Huang. "Power electronics", China Machine Press, (2009) Beijing
[5] IEC 61000-2-2, 2002, Electromagnetic compatibility (EMC)-Part 2-2: "Compatibility levels for low-frequency conducted disturbances and signaling in public low-voltage power supply system"
[6] China State Bureau of Quality and Technical Supervision, GB/T 14549-1993, "Quality of electric energy supply-Harmonics in public supply network", China Standards Press, (1993) Beijing