Harmonic analysis of AC/DC hybrid microgrid

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Abstract. A large number of nonlinear components exist in AC/DC hybrid microgrid, which will cause harmonic pollution and affect power quality. In this paper, according to the diversity, complexity, nonlinearity and mutation characteristics of harmonics, the harmonic analysis of AC/DC hybrid microgrid is carried out by adding harmonic sources. The model diagram of AC/DC hybrid microgrid is built, and the mathematical parameters of harmonics are introduced. Finally, the simulation of microgrid model is constructed based on ETAP, and the harmonic characteristics of AC/DC hybrid microgrid are studied in three cases of static load and equivalent grid using the same harmonic source.

Keywords: AC/DC hybrid microgrid; harmonics; Distributed energy.

1. Introduction

With the development of microgrid technology, AC/DC hybrid microgrid has attracted attention [1]. The implementation of microgrid integrates the advantages of AC microgrid and DC microgrid. In recent years, the application of distributed energy in microgrid has been widely studied. Existing power systems using diesel or coal are facing energy crisis and environmental pollution. The transmission network powered to remote areas has a long transmission distance and suffers huge transmission line loss. Due to these problems, there is a trend to find alternative energy sources. At present, renewable energy distributed generation (DG) has begun to dominate the industrial sector. The use of renewable resources such as wind energy, solar energy or biological energy has become increasingly popular. It is combined with the operation of micro-grid to provide users with clean, reliable, efficient and flexible electricity.

The harmonic problem of power system has attracted people’s attention as early as the 1920s and 1930s. The fundamental reason of harmonic generation in power system is the existence of nonlinear components. With the development of power electronic technology, a variety of power electronic devices are widely used in industry, power, family, so the harm of harmonic generation is increasingly serious. Harmonics will affect the quality of power transmission, causing electrical components heating, premature aging, circuit failure and even burn. Therefore, it is urgent to understand the operation mode of harmonics in the circuit and solve the harmonic pollution. In [2], a feature extraction method of harmonic mutual information based on singular value decomposition (SVD) and fast independent component analysis (FICA) is proposed for the diversity, complexity, nonlinearity and mutation of distribution network harmonics. In [3], the harmonic of AC/DC converter in microgrid is analyzed by
modulation theory method, and the harmonic distortion of voltage is analyzed by simulation. In [4], the law that the current harmonic amplitude of transformer changes nonlinearly with voltage is discussed by using physical analysis. Although the harm of harmonics is serious, scholars have also studied different problems, but the research on the comprehensive harmonic analysis of AC/DC hybrid microgrid is very few, this paper has carried on the research.

The AC/DC hybrid microgrid configuration is shown in Figure 1. On the AC side, the power supply is composed of wind turbine and diesel generator, and the connecting circuit breaker can switch the power supply at any time. On the DC side, photovoltaic array and battery pack are used as the power supply of distributed generators, and AC/DC sub-microgrid is connected by bidirectional converter.

![Hybrid AC/DC microgrid model](image)

**Fig. 1 Hybrid AC/DC microgrid model**

2. Definition of harmonics

The waveform generated by the voltage and current in the grid under ideal operation is standard sine wave, but in reality, the waveform generated by the grid under the influence of various nonlinear components in the circuit will be distorted to varying degrees. The harmonic generated in the microgrid, like the traditional grid, is the fundamental frequency multiple sine wave. The nth harmonic voltage contains rate $HRU_N$ is the ratio of the nth harmonic voltage to the fundamental voltage. The expression is

$$HRU_N = \frac{U_n}{U_1} \times 100\%$$

The nth harmonic current contains rate $HRI_N$ is the ratio of the nth harmonic current effective value to the fundamental current effective value. The expression is

$$HRI_N = \frac{I_n}{I_1} \times 100\%$$

Harmonic voltage content $U_H$ and harmonic current content $I_H$ are:

$$U_H = \sqrt{\sum_{n=2}^{\infty} U_n^2}$$

$$I_H = \sqrt{\sum_{n=2}^{\infty} I_n^2}$$

The total distortion of voltage harmonics $THD_u$ and current harmonics $THD_i$ are respectively:

$$THD_u = \frac{U_H}{U_1} \times 100\%$$

$$THD_i = \frac{I_H}{I_1} \times 100\%$$
3. Application of ETAP simulation

The circuit diagram of AC/DC hybrid microgrid is designed in ETAP. AC bus is connected to DC bus to form hybrid connection according to simulation analysis. Wind turbines (WTG) and photovoltaic systems (PV) are located on the AC side, using diesel engines (Gen1) as backups to prevent blackouts. The system is connected to the existing equivalent grid to provide additional power demand for new loads. In the DC side, with the battery as the power supply, the inverter and rectifier are used to realize the interconnection of DC bus and AC power supply, and the output of the battery circuit is improved. In addition, the PV system can be connected to the DC side circuit, but because the ETAP 12.6.0.11814 version cannot connect PV to the converter and DC load, it is connected to the AC side.

The circuit has two main buses, namely AC bus (Bus2) and DC bus (DCBus2). Both buses are 400 V connected by an interconnected inverter. AC bus has 80 kVA load (Lump1) and 80 kVA static load (Load1), DC bus load (dcload1) power is 50 kW. The AC bus is supplied by wind power (80 kW), diesel power (70 kW) and photovoltaic power (300 V, 30 kW) The DC bus is connected with two batteries and the battery capacity is 495 Ah and 285 Ah respectively. The rated voltage of equivalent grid is 35 kV, 15 MVA, and the rated capacity of transformer is 400 MVA, with a conversion ratio of 35/0.4 kV. Figure 2 shows the single line diagram of the AC/DC hybrid microgrid based on ETAP design.

The static load under bus 6 is added to the harmonic source for harmonic analysis, and the current source of DCS5006P is selected as the harmonic source. The spectrum and waveform structure are shown in Figure 3 and Figure 4.

\[ \text{THD}_i = \frac{I_N}{I_i} \times 100\% \]
Case 1: Based on the added harmonic source, AC microgrid Load1 is a nonlinear load, and other loads are linear loads. Bus 2, 3, 4, 5 and 6 are 0.4KV, and the parameters of each device on them are consistent and the length of the cable in the circuit is set to one kilometer. The simulation results of voltage waveform on each bus based on load harmonic are shown in Figure 5 and the spectrum analysis is shown in Figure 6.
It can be seen from the simulation figure that due to the directional connection of the nonlinear load, the maximum distortion is the bus 6 closest to the nonlinear element, and the total current distortion THD is 15.21%. In the spectrum diagram, it can be observed that the fifth harmonic has the greatest impact on the microgrid, and the voltage spectrum is 1.75%. The bus 1 is farthest from the harmonic source and the fluctuation is small, which still keeps periodic and stable operation.

Case 2: The equivalent grid on bus 1 is added with harmonic source for harmonic analysis, and the current source of DCS5006P is still selected as the harmonic source. Based on the harmonic source, the transformer of AC microgrid is nonlinear load, and other components are linear load. Bus 2, 3, 4, 5 and 6 are 0.4KV, and the parameters of each device on them are basically the same, and the length of the cable in the circuit is set to one kilometer. The voltage waveform simulation results of each bus based on the equivalent grid are shown in Figure 7, and the spectrum analysis is shown in Figure 8.

It can be seen from the simulation diagram that the bus 1, which is closest to the harmonic source, fluctuates greatly when the harmonic source exists in the equivalent grid, and the total current distortion THD is 16.81%. In the spectrum diagram, it can be observed that the fifth harmonic has the greatest impact on the microgrid, and the voltage spectrum of bus 1 is 2.3%. The remaining bus is 0.4KV, the fluctuation amplitude is small and the waveform is close.

Case 3: The load and equivalent grid are added to the model DCS5006P current source as the harmonic source for harmonic analysis, the voltage waveform simulation results of each bus are shown in Figure 9, and the spectrum analysis is shown in Figure 10.

It can be seen from the simulation diagram that the bus 1, which is closest to the harmonic source, fluctuates greatly when the harmonic source exists in the equivalent grid, and the total current distortion THD is 16.81%. In the spectrum diagram, it can be observed that the fifth harmonic has the greatest impact on the microgrid, and the voltage spectrum of bus 1 is 2.3%. The remaining bus is 0.4KV, the fluctuation amplitude is small and the waveform is close.

Case 3: The load and equivalent grid are added to the model DCS5006P current source as the harmonic source for harmonic analysis, the voltage waveform simulation results of each bus are shown in Figure 9, and the spectrum analysis is shown in Figure 10.
When the two harmonic sources are all put into the circuit, the total current distortion THD is 3.41%, which decreases compared with the case of single harmonic source. In the spectrum diagram, the voltage percentage of each bus decreases with the increase of different harmonic times compared with case 1 and case 2, and the voltage distortion degree of the fifth harmonic is also improved.

In summary, the distance determines the influence degree of harmonic source on the bus, the mutual interference of multiple harmonic sources will appear iteration with the period deviation, and no matter how the type or size of harmonic source changes, the voltage distortion of the bus is not decreased, which shows that the DC bus has a good blocking effect on the harmonic structure.

4. Summary
In this paper, the harmonic source is added to the AC/DC microgrid, and ETAP software is used for experimental simulation in three cases. The conclusion is obtained based on the analysis of experimental data and simulation graphics. When the harmonic source appears in the power network, the bus far from the harmonic source is less affected by harmonic, and the bus nearer is more affected by harmonic. When there are multiple harmonic sources in the operation of micro-grid system, when the harmonic source period in the same direction will cause the bus harmonic phase superposition, the harmonic cycle will cause the bus harmonic offset. The experimental conclusions based on this study can provide guidance for the planning and power quality control of AC/DC hybrid microgrid. The next step can calculate the capacity of the filter, the corresponding parameters and compare the advantages and disadvantages of different types of filters, select the appropriate filter to restore the steady-state operation of the grid system.

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