PAPER • OPEN ACCESS

The study of the harmonic impedance measurement

To cite this article: Hongtao Shi *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **490** 072064

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

The study of the harmonic impedance measurement

Hongtao Shi[*], Yongping Guo , Weiwei Zhang , and Juntao Pan

School of Electrical and Information Engineering, North Minzu University, Yinchuan, China

*Corresponding author e-mail: peneg@sina.com

Abstract. Harmonic impedance of system is the important parameter for the harmonic suppression and it is also useful to the design of filter, circuit analysis, et al. Generally, a controllable harmonic perturbation is used and injected into the target circuit port, and then harmonic impedance can be captured by the corresponding harmonic voltage and current. In this paper, a circuit design of harmonic impedance measurement is proposed, in which each functional modules is comprised of analogue circuit, and it can generate a controllable current disturbance into the target system. The system impedance is calculated by using the current and the corresponding voltage, which are captured by the data acquisition circuits. By using the PSCAD, a simulation of measurement circuit is established. In simulation, the measuring results are coincident with the theoretical value, which validate the effectiveness of the circuit design.

1. Introduction

The harmonic impedance is a very useful parameter to harmonic suppression and power system analysis [1-6]. In the power quality analysis and control system design, the character of harmonic imedance is the improtance reference. Recently, a harmonic impedance based stability criteria is proposed, by using which the stability of power electronic circuit can be judged. In this methd, the ratio of output harmonic impedance and input harmonic impedance of the special ports in power electronic system is used. Early on, the stability analysis based on harmonic impedance is used to the DC cascade system, the harmonic impedance of which can be measured precisely. Recently, several studies is developed to the AC cascade system stability analysis by using harmonic impedance based stable criteria. In [3-4], the harmonic impedance criteria is used to discuss the stability of AC cascade power electronic system.

As abovementioned, the measurement of harmonic impedance is the key parameter when in the power quality analysis or using the harmonic impedance criteria. Generally a disturbance signal is injected into the target system. At the same time, the perturbation signal and the corresponding system response signal can be obtained. And then the system impedance is calculated by using the voltage and current which come from the FFT of the disturbance signal. In the DC system [5], the voltage and current of the system are stable, then the voltage and current disturbance can be easily captured, namely the harmonic impedance can be calculated. However, in the AC system, the voltage and current of system are fluctuates periodically, resulting in the difficulties of the disturbance signals injection and disturbance signals extraction. In addition, the disturbance signal is always designed large because of the high power of AC system [6].

There are several studies for the harmonic impedance measurement. In the past studies, the perturbation signal is generated by switching the reactive compensation capacitor in AC system[7]. By

measuring the disturbance current and voltage resulting from the capacitor switching, the harmonic impedance can be obtained. However, in this case, the disturbance current and voltage are uncontrollable, the frequency bandwidth of harmonic signal may be incomplete, and then the measurement accuracy of harmonic impedance should be improved. In [8], a measurement device is proposed, it inject specific disturbance into system, and then the harmonic impedance can be captured accurately.

In this paper, a circuit design of harmonic impedance measurement is proposed. Each circuit functional modules of this circuit is designed by analogue circuit, which can generate high frequency harmonic signal and which can be injected into the target system. And then the disturbance of system can be captured, the harmonic impedance can be calculated.

2. The calculation of harmonic impedance

Harmonic impedance of system is the impedance of specific port in system with different frequency. For the impedance calculation, the voltage disturbance u and the current disturbance i of the system specific port are extracted. The harmonic voltage $U(j\omega)$ and current $I(j\omega)$ can be obtained by the FFT of the disturbance signals u and i, which can be shown as:

$$U(j\omega)=F(u) \tag{1}$$
$$I(j\omega)= F(i) \tag{2}$$

In this case, the harmonic impedance $Z(j\omega)$ can be calculated by the following formula:

$$Z(j\omega) = \frac{U(j\omega)}{I(j\omega)} \tag{3}$$

After the calculation of impedance in each specific frequency gradually, the complete harmonic impedance value can be obtained.

3. Design of the harmonic impedance measurement circuit

3.1. Disturbance signal demand

As abovementioned, for the harmonic impedance measurement, the first step is capture the voltage disturbance and current disturbance. Generally, there are two methods to realize the harmonic signal extraction. The first method is based on the statistical analysis, in which the system operating data is collected and the harmonic current and harmonic voltage can be calculated out by the statistical algorithm. In this case, all the data come from the normal operating mode of system. Therefore the harmonic analysis will not affect the system operation. The second method is based on the disturbance injection, in which a controllable disturbance is obtained and this disturbance is added to the target port. This injected perturbation with the system responded voltage or current are captured at the same time. And then, the harmonic voltage and harmonic current can be obtained by FFT. In this case, the perturbation is controllable, therefore the measurement has high precision.

According to the signal types, the disturbance injection can be divided into two categories. The first is named sine frequency sweep method. By using this method, the disturbance generator can produce sine current or voltage in each frequency. These sine perturbations are amplified and then injected into the target circuit port gradually. At the same time, the target system will generate responded signals. By using this method, it has high measurement precision, with long measurement time. The second method is that the injected signal is a specific waveform current or voltage, which contains a series sine signals by FFT. Therefore the harmonic voltage and harmonic current can be obtained by only one or two signals injection, which can save measurement time. However, the measurement precision may drop because of the signal attenuation.

3.2. System configuration

In this paper, a circuit design of harmonic impedance measurement is proposed, which can inject both sine signal and specific signal into the AC system, and then it captures the corresponding voltage and current disturbance. The circuit configuration is shown as figure 1, which contains signal generator, power amplifier, phased-controlled circuit, et al.
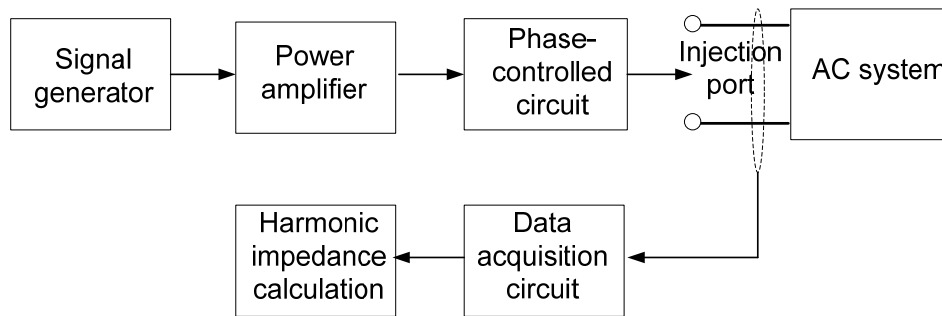
Figure 1. Configuration of impedance measurement circuit.

3.3. System principle

The harmonic impedance measurement circuit designed in this paper can inject sine or other specific signals into the target system. Therefore the input of the device is a controllable signal generator which can generate sine signal, square signal, triangle signal, et al. The signal generator is realized by analogue circuit which can generate high frequency signals.

The signal generated by the pre-stage circuit is a weak voltage. Therefore it must be amplified before injected into the system. The power amplifier designed in this paper is developed by transistor based amplified circuit which has a broad frequency band. In order to obtain high power, the power amplifier is comprised by multi-amplifier paralleled.

The voltage and current of AC system are fluctuates periodically, including the amplitude and frequency. Therefore the phase of the disturbance signal must be controllable. The measurement circuit designed in this paper contains a phase-controlled circuit which can change the phase difference between the disturbance signal phase and the voltage of AC system, and then the phase and waveform of injected current can be controlled.

The data acquisition circuit contains sensor and data acquisition card. The current sensors and voltage sensors are used to sense the disturbance signal that injected into the AC system and its system respond signals, respectively. Then these signals are transferred to data by data acquisition card. At last, after FFT, the harmonic voltage and harmonic current can be obtained. Harmonic impedance of circuit specific port is calculated by the voltage and the current.

4. Simulation validation

A simulation model of harmonic impedance measurement circuit is developed in PSCAD. In this model, a RL and AC source net is used to simulate the AC system. The simulation voltage waveform of AC system is shown as Fig.2. The harmonic impedance measurement circuit designed as the aforementioned generates current disturbance for AC system.
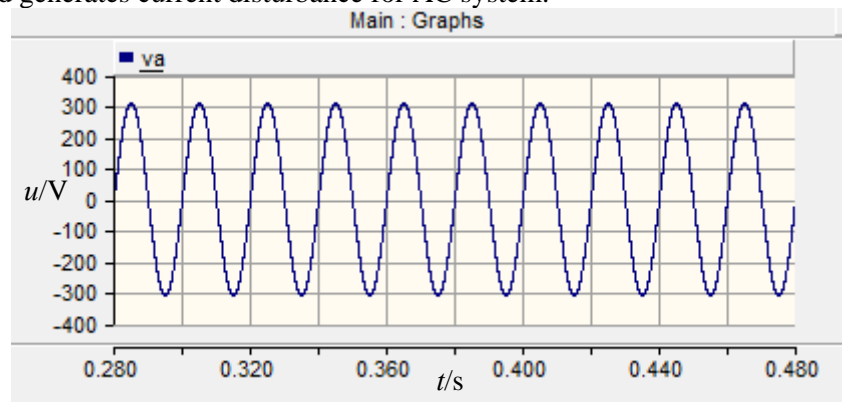

Figure 2. Simulation voltage waveform of AC system

After the circuit operation simulation and data computing, Harmonic impedance of circuit specific port is calculated, and the impedance curves is obtained, as shown in Fig.3. By the analysis of the impedance curves, the harmonic impedance character is resistor-inductance, which is decided by the

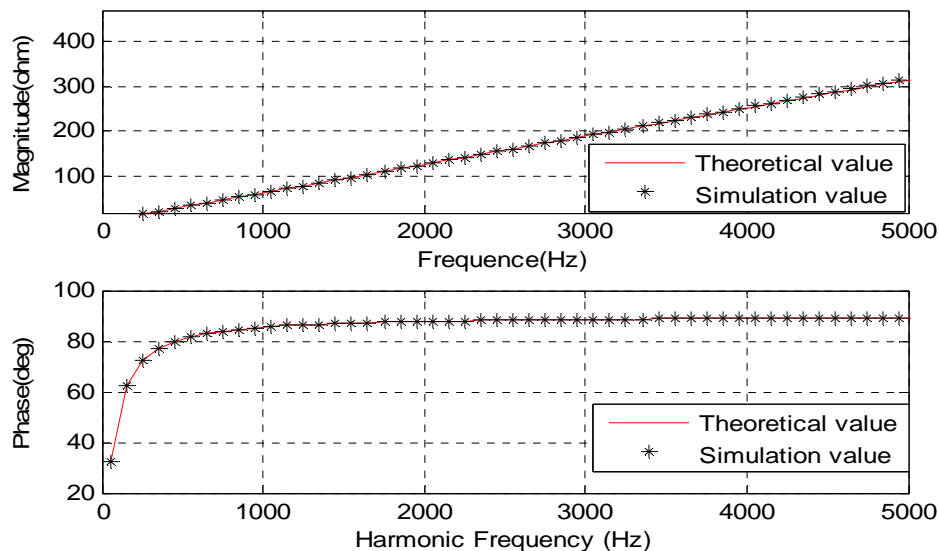circuit configuration of the AC system. The measurement impedance is agreed with the theoretical impedance.

Figure 3. Simulation and theoretical results.

5. Conclusion

Harmonic impedance is the key parameter when the impedance based stable criteria is using to analyze the stability of system. Therefore it is meaningful to develop impedance measurement method and exploit circuit impedance measuring equipment. In this paper, a harmonic impedance measurement circuit is proposed, which contains signal generator, power amplifier, phased-controlled circuit, et al. By using this circuit, both sine signals and other specific signals can be generated and injected into the AC system. And then after the data acquisition and computing, the harmonic impedance of circuit specific port is calculated. A simulation mode is developed in PSCAD. The effectiveness of the measurement circuit design is validated by simulation. And the measurement circuit is practical in application.

References

[1] R.D. Middlebrook. Input filter considerations in design and application of switching regulators[C]. IEEE Industrial Application Society Annual Meeting. Chicago, USA: IEEE, 1976, pp.366-382
[2] E.A.A. Coelho, P.C. Cortizo, and P.F.D. Garcia, "Small-Signal Stability for Parallel -Connected Inverters in Stand-Alone AC Supply Systems," IEEE Trans on Industry Applications, 2002, 38(2) :533 -542.
[3] X. Feng, J. Liu, F.C. Lee. Impedance specifications for stable DC distributed power systems[J]. IEEE Trans. Power Electronics, 2002, 17(2):, pp.157-162.
[4] J.J. Liu, X.G. Feng, F.C. Lee. Stability margin monitoring for DC distributed power systems via perturbation approaches[J]. IEEE Trans. on Power Electronics, 2003, 18(6), pp.1254-1261.
[5] T. Wu, X.B. Ruan. Input Impedance Analysis of Load Converters in the Distributed Power System[J]. Proceedings of the CSEE, 2008, 28(12), pp.20-25.
[6] H.T, Shi, Z. Yang, X.L. Yue, et al. Calculation and Measurement of Harmonic Impedance for A Microgrid Operating in Islanding Mode [C]. 2012 IEEE 7th International Power Electronics and Motion Control Conference - ECCE Asia, pp. 356-361
[7] Y. lv, Z. Xu. Network Harmonic Impedance Measurement Using Capacitor Switching[J]. High Voltage Engineering, 2009,35(7):1780-1784.
[8] H.T, Shi, F. Zhuo, Z. Yang, et al. The Study of Harmonic Impedance measurement for AC system based on an improved modulated current injection method[J].Transactions of China Electrotechnical Society, 2015, 30(8):257-264.