

# Design, Control and Simulation of a Non-linear-Load Current Disturbance Generator with Energy Feedback Technology

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**Abstract-** This paper deals with a high-powered, low-loss and digital current disturbance generator. It can produce harmonic current, active current, inductive reactive current and capacitive reactive current, so it is able to simulate kinds of actual industrial situations. By using energy feedback technology, the generator feeds the power consumed by the current disturbance back to the grid. Thus, it can save a lot of energy, and the lab will need less power capacity. The unit of feedback can also compensate the harmonic current and reactive current, so the generator has little impact on the power grid. Simulation result verifies the correctness of analysis and the validity of the project.

**Keywords-** Current Disturbance, Energy feedback, Control, Energy Conservation

## I. INTRODUCTION

With various electronic equipments, such as electric arc furnace, electric traction locomotives and other non-linear load, increasing in electricity distribution system, the power quality of power system is deteriorating. As the continuous research on power quality and the development of power electronics technology, power quality instruments and a variety of power quality compensation devices developed rapidly. Thus, how to test the performance of these equipments before formally putting into operation conveniently becomes extremely important.

At present, some specialized laboratories researching power quality, such as the United States Wichita State University (WSU) Power Quality Research Center and Texas A&M University Power Quality Simulation and Testing Laboratory, have special devices to produce power quality disturbances [1]. However, these power quality disturbance devices are based on the voltage amplifiers or current amplifiers. The output current or voltage of these devices is very small, so the load capacity of them is extremely weak. As producing high-power current disturbance costs too much, presently, the current power compensation devices and power quality instruments should be transported to the industrial scene for testing. So, it requires longer test cycle and higher cost. And there is no uniform testing standard either.

In this paper, the design, control and simulation of a high-powered, low-loss and digital current disturbance generator is given in detail. The simulation of the generator

in three-phase system is done in PSIM. The simulation results verify the performance and feasibility of the proposed current disturbance generator.

## II. STRUCTURE OF THE CURRENT DISTURBANCE GENERATOR

A schematic diagram for a non-linear load current disturbance generator is shown in Fig.1. The current disturbance generator consists of DSP controller, Disturbance Occurred Unit (DOU), Feedback Unit (FU), a dc bus capacitor and two LCL-filters, which are used for elimination of switching harmonics. The Disturbance Occurred Unit is a Voltage Source PWM Rectifier, which produce current disturbance in accordance with the instruction current controlled by the DSP controller. The Feedback Unit uses an IGBT Inverter to feed the energy consumed by the current disturbance back to the grid. The DOU and the FU are connected through a dc bus capacitance, and they form an AC-DC-AC structure.

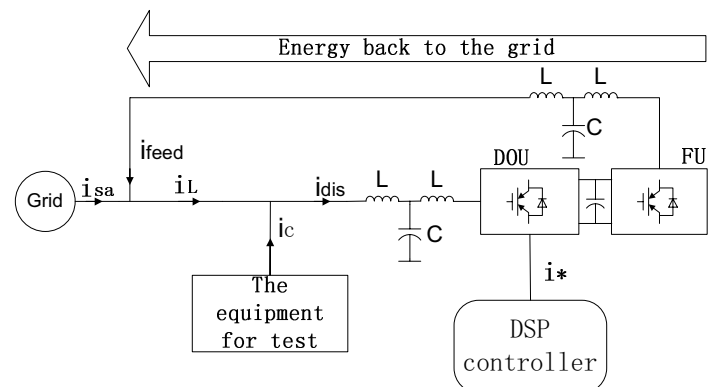


Fig.1 the Structure of the Non-linear Load Current Disturbance Generator

## III. CONTROL OF THE DISTURBANCE CURRENT

The aim of the proposed generator is to generate current disturbance consist of harmonic current, active current, inductive reactive current and capacitive reactive current. The current disturbance in accordance with the instruction current is produced by the DOU, and the instruction current is generated by the DSP controller. Feedback Unit feed energy back to the grid. Thus, it can be

decomposed into three parts: generating of instruction current, control of the Disturbance Occurred Unit and Control of the Feedback Unit.

#### A. Generating of Instruction Current

The instruction current is exactly the current disturbance that we wish the proposed generator to produce. The instruction current contains some or all of harmonic, active and reactive components. Fig.2 shows the principle to generate the instruction current.

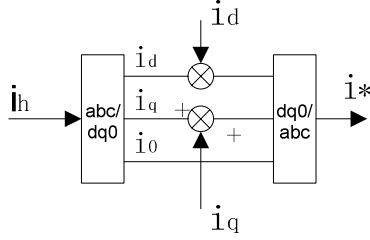


Fig.2 schematic diagram of the instruction current generating

$i_h$  is the harmonic component of the instruction current. The controller first calculates all harmonics we decide to produce, and then adds them together. It is complex to generate fundamental active and reactive current, as the controller should cost a large amount of computation. Here is a method to generate active and reactive current based on dq0 transform.

Supposing the three-phase voltage of infinite power grid is symmetric and has no distortion, that is:

$$E_{abc} = U_m \begin{bmatrix} \sin(\omega t) \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \quad (1)$$

Active current is as follows:

$$i_{pabc} = I_{pm} \begin{bmatrix} \sin(\omega t) \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \quad (2)$$

Dq0 transformation:

$$i_{pdq0} = P i_{pabc} = P I_{pm} \begin{bmatrix} \sin(\omega t) \\ \sin(\omega t - \frac{2\pi}{3}) \\ \sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} = I_{pm} \begin{bmatrix} 0 \\ -1 \\ 0 \end{bmatrix} \quad (3)$$

Reactive Current:

$$i_{qabc} = I_{qm} \begin{bmatrix} \sin(\omega t \pm \frac{\pi}{2}) \\ \sin(\omega t \pm \frac{\pi}{2} - \frac{2\pi}{3}) \\ \sin(\omega t \pm \frac{\pi}{2} + \frac{2\pi}{3}) \end{bmatrix} \quad (4)$$

Dq0 transformation:

$$i_{q dq0} = P i_{qabc} = P I_{qm} \begin{bmatrix} \sin(\omega t \pm \frac{\pi}{2}) \\ \sin(\omega t \pm \frac{\pi}{2} - \frac{2\pi}{3}) \\ \sin(\omega t \pm \frac{\pi}{2} + \frac{2\pi}{3}) \end{bmatrix} = I_{qm} \begin{bmatrix} \pm 1 \\ 0 \\ 0 \end{bmatrix} \quad (5)$$

According to above formulas, after dq0 transformation, active current is only related to  $i_q$ , and reactive current is only related to  $i_d$ . Besides,  $i_q$  and  $i_d$  are both DC component, whose size is as same as the amplitude of corresponding active or reactive current.

#### B. Control of Disturbance Occurred Unit

Fig.3 shows the control method of the current disturbance produced by DOU, which is a current control loop. The reference current  $i_*$  is the instruction current generated by the DSP controller, the feedback current is the actual current  $i_{dis}$  generated by DOU. A PI controller is used to turn the difference between the reference current  $i_*$  and the feedback current into the command signal of the IGBT rectifier.

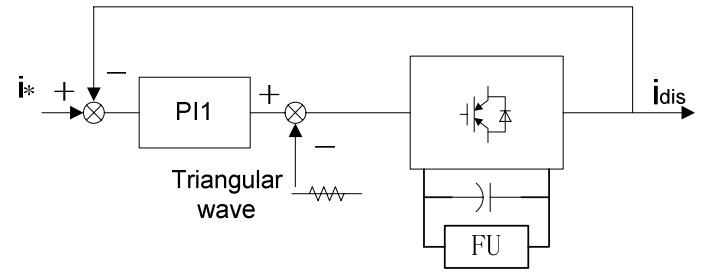


Fig.3 Trace Control of the Current Disturbance

#### C. Control of the Feedback Unit

The voltage stability of the dc bus capacitor is essential for the stability of the whole system. According to the instantaneous reactive power theory[7], the instantaneous power of the PWM converters will not lead to energy exchange between DC side and AC side. Supposing no loss, all the instantaneous active power in AC side will be

delivered to the DC side. That is, the energy exchange between AC and DC side depends only on the instantaneous active power, and the reactive power has nothing to do. Therefore, to make the voltage of the dc bus capacitor steady, we only need to control the active power (that is, active current).

As the formulas deduced above, the active current is only relevant to  $i_q$ . Another PI controller is used to make the dc bus capacitor steady, as showed in Fig.4.

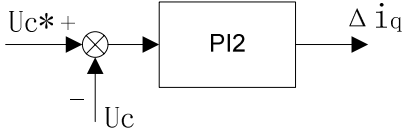


Fig.4 dc bus capacitor voltage stability

The voltage stability of the dc bus capacitor is achieved by Feedback Unit. The Feedback Unit is mainly used to feed the power consumed by the current disturbance back to the grid, and compensate the harmonic current at the same time. An inverter is used to turn power in the dc bus capacitor into alternating current, which will be fed back into the power grid. Fig.5 shows the control block diagram of the Feedback Unit.

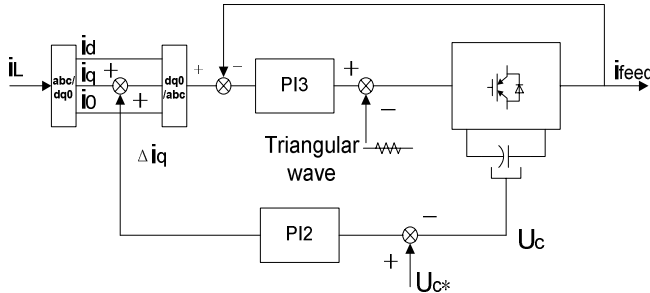


Fig.5 control block diagram of the Feedback Unit

$i_L$  is the current having been compensated by the equipment for test. The sum of  $i_L$  and the active current keeping dc bus capacitor steady is the reference current of the Feedback Unit. Based on dq0 transform, it is easier to add them together. The generating of feedback current is also use current control loop as the disturbance current. With the feedback current tracing the reference current, the whole system will need very little power from the grid. And if there is harmonic component in current  $i_L$ , the FU is also able to compensate it, so the generator has little impact on the power grid.

#### IV. SIMULATION RESULT

PSIM is used to simulate the proposed disturbance generator and its control method. As b-phase and c-phase have the same waveform with a-phase, only different in

phase, the simulation results are only in a-phase. Fig.6 shows 0.25 times source voltage waveform. Fig.7 shows the disturbance current waveform and frequency spectrum. The instruction current contains 5, 7, 11, 13 harmonics, active and reactive components. The amplitudes of each harmonic are 8.5, 4.2, 3.5 and 2.4 respectively. The amplitude of active current is 50, and the amplitude of reactive current is 30 inductively. Fig.8 shows the feedback current waveform and frequency spectrum. It can be seen that the disturbance current and feedback current are similar. Fig.9 shows the source current waveform. Compared with disturbance current, the source current is very little. There are also some harmonics, as it is mainly from the current keeping dc bus capacitor steady. Beside of these, there are only high harmonics.

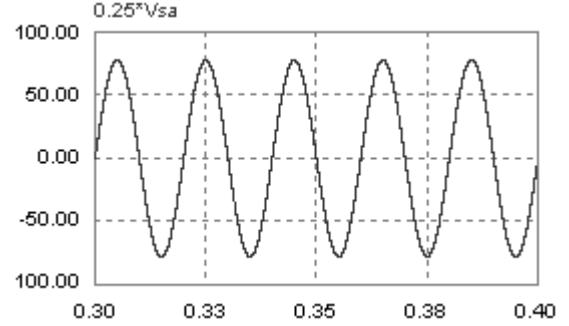


Fig.6 0.25 a-phase source voltage waveform

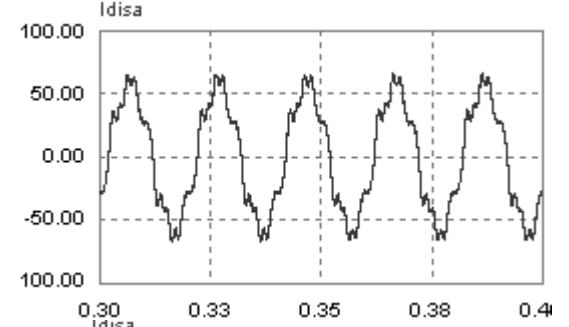


Fig.7 a-phase disturbance current waveform and frequency spectrum

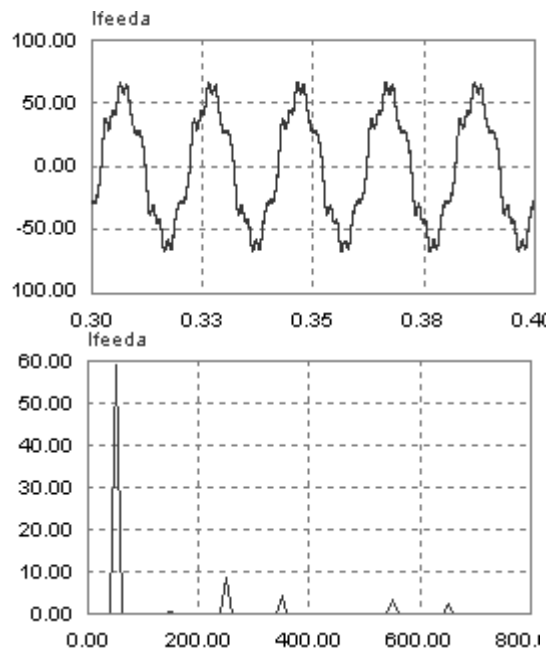


Fig.8 a-phase feedback current waveform and frequency spectrum

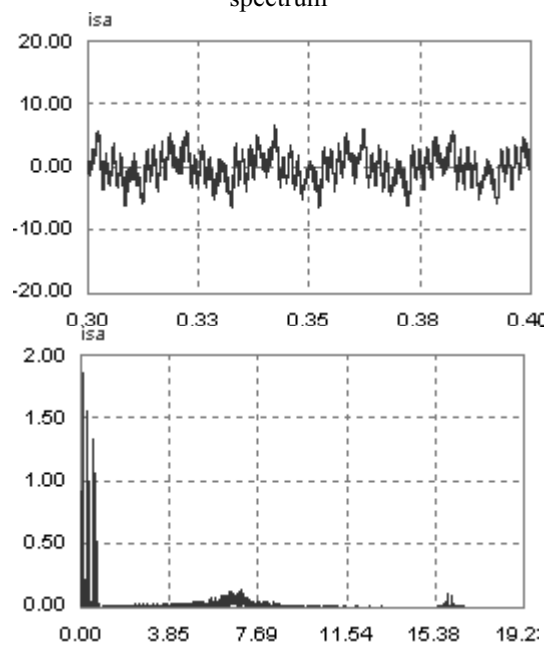


Fig.9 a-phase source current waveform and frequency spectrum

## V. CONCLUSION

In this paper, a high-powered, low-loss and digital current disturbance generator is proposed, which can produce disturbance current to simulate kinds of actual industrial situations. The structure of the generator is designed, and the control method is discussed in detail. A simulation is also done to verify the performance of the generator. Simulation results show that the proposed generator can produce high-powered disturbance current and have little impact on the power grid. Besides, the

generator is also able to simulate asymmetric current and impact current, which is similar to the disturbance current in principle.

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