EMC'04/Sendai

1D1-6

NEW TECHNOLOGIES OF HARMONIC SUPPERESSION CONTROL IN POWER SYSEM

Nobuyuki Matsui[*], Atsuo Kawamura[‡], Tokuo Ohnishi[†], Takaharu Takeshita[*], Hiroyuki Ukai[*], Makoto Saito[*], Kouhei Ohnishi[§], and Koichi Nakamura[*]

[*] Nagoya Institute of Technology, [‡] Yokohama National University,
[†] Tokushima University, [§] Keio University

Abstract: With recent currency of power electronics devices, the harmonic pollution in power system becomes a serious problem. This research presents new technologies of the harmonic suppression control in power system. In order to block the outflow of harmonic current form power consumers, two new techniques of harmonic suppression control using the active filters are proposed. On the other hand, as recent utility power distribution system becomes wider and more complex, advanced harmonic measurement, analysis and control technologies are required. Therefore this paper proposes the harmonic modeling based on the synchronized measurement system at multi-points in distribution system and the new harmonic compensation methods, the route control and modal control, in power system.

Key words: Harmonics, Suppression control, Distribution system, Active filter, Synchronized measurement system

1. Introduction

In accordance with the recent development of the semiconductor devices, power electronics technology is applied to various fields and contributes advanced control, improvement of power quality, energy saving, and so on. On the other hand, however, it also causes a serious problem of harmonic pollution, as the result, harmonics give serious damage to electric and electronic devices. The harmonic problem originally attributes (1)the suppression and the tolerance for harmonics of individual equipment, and (2)the identification of harmonic sources in distribution system and their suppression. In order to cope the later, power devices such as LC filters and active filters are introduced. In particular, the harmonic compensation techniques using active filters have been received a great deal of attention.

In order to prevent the harmonic pollution in power system, two methods are possible. One is to block the outflow of harmonic current form power consumers, the other is to suppress harmonic voltage in distribution system. Due to the resent easing of restrictions of electric utilities, the participation of IPPs (Independent Power Producers) increasingly makes distribution system complex. Therefore, in order to precisely analyze harmonic phenomena, it is dispensable to construct the high accuracy measurement system, in which has a function that can synchronously measure harmonics at multi-points in power system.

From these backgrounds, in this paper, the new control technologies to suppress harmonic interference are proposed in both consumers and distribution system.

2. Harmonic Suppression Control in Consumer

2.1 Active Filter for Consumer Use[1]

Fig.1 shows the schematic diagram of the parallel active filter with the voltage fed type PWM inverter. Many types of control methods based on the control variables shown in the circuit have been proposed. Their control quantities investigated are as follows.

1) Load harmonics current detection control (i_o)
2) AC source line current detection control (i_s)
3) AC load terminal voltage detection control (e_o)
4) AC side voltage control of PWM inverter (e_c)
5) Combination control with 3) and 4)
6) Combination control with 2) and 3)

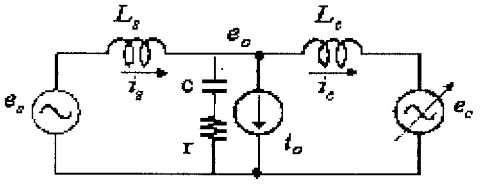


Fig.1 Main filter circuit and control variables

The control system of the conventional active filter based on the first control scheme 1) is somewhat complicate and it has inherent problems such as mismatch gain for the two current sensors.

The second control system 2) is very simple and it has not such problems. However, alternative unstable oscillation problems arise. So, various types of compensation method for this control method have been investigated in this project too. It was shown that the source current differentiation feed back method is effective for phase delay compensation.

The third and fourth control method 3) 4) are also proposed and investigated. These control systems can compensate not only the harmonics current but also the line voltage distortion. However, large amount of current may flow to compensate directly the voltage distortion for the control method 3). On the other hand, the control method 4) is very simple. But, enough filtering characteristics may not be obtained because of the indirect control through the coupling inductance L_b. We proposed and investigated too the combined control method 5) not to flow the excessive compensation current by adjusting the voltage control terminal point.

The last control method 6) is also very useful to suppress the harmonics current and to improve the terminal voltage at the same time. By the admittance control across the load terminal for harmonics, the terminal voltage may be improved in addition to the enough current active filter characteristics. This control system was developed and it will be presented in near future.

2.2 Line Current Detection Type Active Filter for Resonance Suppression[2]

The source current detection type active filter(AF) is attractive in the sense that only one sensor is required and only one AF is used to compensate all harmonics. In general, the line current detection type AF detects line current harmonics i_{sh} and flows the compensation current i_{af} to the line current. Usually the general proportional control can be written as,

$$i^*_{af} = -K_a i_{sh} \qquad (1)$$

If there is no LC filter(LCF), all harmonics can be reduced by increasing the gain K_a. When a LCF is connected parallel as shown in Fig. 3, a resonance between the AF and the LCF occurs and the specific harmonics will be increased. This problem is called the anti-resonance problem. It is shown in Fig.4 that almost all harmonics are reduced but the 7th-order harmonic cannot be compensated by the proportional control AF. Based on the control theory, a disturbance-observer- based AF is proposed to solve the anti-resonance problem in this paper. The control block diagram is shown in Fig.2.

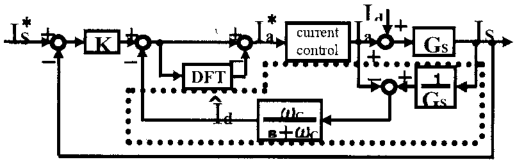


Fig. 2 The disturbance-observer-based AF

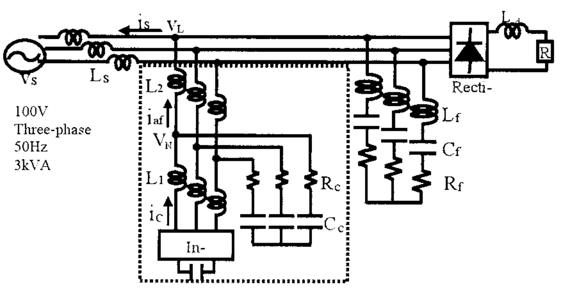


Fig. 3:Experimental circuit

The disturbance observer consists of the nominal inverse system of the plant $\frac{1}{G_{sn}}$ and the low pass filter. It estimates the harmonics current i_d, which contains the harmonics generated by the non-liner load, using the source current i_s and the AF current i_{af}. Moreover it compensates i_d by adding the inverse phase current of the estimated current $\hat{i}_d$ to the AF current reference. The cut off frequency ω_c for the low pass filter must be selected larger than the harmonic frequency to be compensated. The comparison between the proportional control and the proposed disturbance-observer-based control is shown in Fig.4. It is clear that the proposed disturbance-observer-based control has better compensation performance than the proportional one in the wide frequency range, especially for the low order harmonics.

Fig.3 shows the experimental circuit which has a three phases, 100V, 2kVA voltage source. The experimental results are shown in Fig.4 with ◊ (no AF), +(proportional AF) and □(observer AF). It shows that the experimental and the calculation results are in good agreement. These experimental results verify that the proposed control is effective in improving the compensation performance.

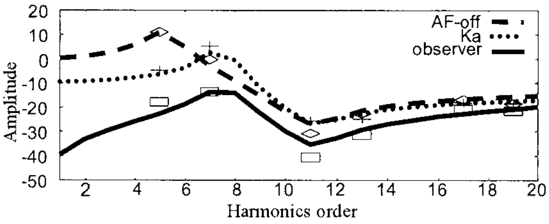


Fig. 4 Compensation characteristics

2.3 Harmonic Suppression in Consumer[3]

The control system of the active filter for consumer may be unstable under the low load-impedance for harmonics due to the power factor correction capacitor as shown in Fig. 5. In order to improve the stability of the control system, the authors propose the control scheme using the complex gain K in (2).

$$i_c = K i_{sh} \qquad K = K_m e^{j\phi} \qquad (2)$$

where i_c is the compensation current of the active filter and i_{sh} is the harmonic components of the source current i_s . The compensation phase ϕ is automatically chosen by the following equation in the controller.

$$\phi = \arg\{(Z_s + Z_L)/Z_L\} \qquad (3)$$

where Z_s and Z_L are the line and load impedances, respectively. Fig. 6 shows the experimental waveforms using the 200 V, 3.46 kVA laboratory experimental system in Fig. 5. Fig. 6 (a) shows the source current waveform i_s without the active filter. The THD of the source current is 45.1 %. Fig. 6 (b) shows the current waveforms using the conventional control scheme. The THD of the source current i_s increases to 62.9 % and the control system is unstable. Fig. 6(c) shows the current waveforms using the proposed control. The THD of the source current is improved to 3.6 %. The good effect on the compensation for the harmonic current is obtained and the stable control can be realized.

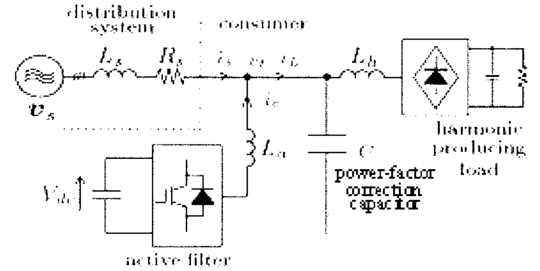


Fig. 5 Consumer Model

3. Harmonic Suppression Control in Distribution System

3.1. Harmonics Modeling Based on Multi-points Synchronized Measurement System[4]

Since harmonic flows instantaneously propagate in wide area distribution system, it is necessary to precisely measure harmonic flows at each node of power system. Furthermore in order to know the real time flow of harmonics, the synchronized measurement system is required. The concept of the proposed synchronized measurement system is shown in Fig.7. In the figure, each terminal is a measurement system assigned at each node or a significant power receiving end. It has the function which synchronously measures voltage/current and analyze harmonics in real time. The harmonic flow at each node is determined by harmonic RMS values and phases of voltage and current. Time synchronization is realized by using the GPS signal. The measured and analyzed harmonic data are transferred to a central monitoring station with the absolute time data. The central monitoring station is constructed by the high-end processor which analyzes and visualizes harmonic information from terminals.

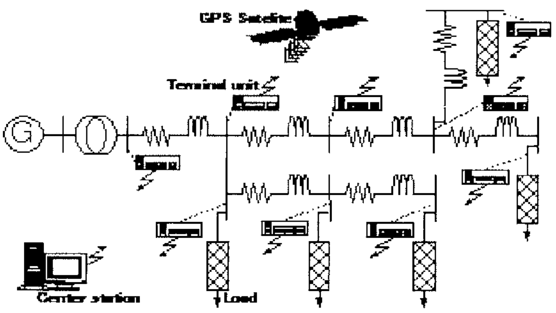
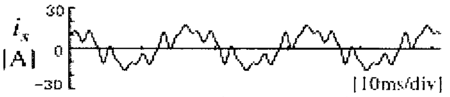
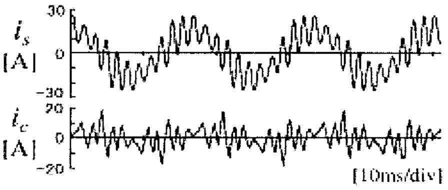


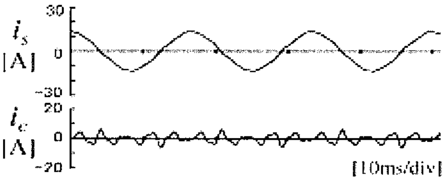
Fig. 7 Multi-points synchronized harmonic measurement system



(a)Without active filter



(b)Conventional control scheme



(c) Proposed control scheme

Fig. 6 Experimental current waveforms

3.2 Route Control[5]

The power system is a large and complex system which consists of power sources, transmission lines, transformer substations, loads, and other power facilities. These components are organically connected each other, and hence each component can be regarded as a subsystem of a whole system. Since practical control procedures for harmonic compensation are achieved by changing transmission route and/or inserting phase modifiers, it is desirable to treat power system as decentralized system and systematically deduce the switching strategy of system connections.

The proposed "route control" implies to reconfigure the system in which harmonic pollution occurs to the desired system in which harmonic flow is reduced by changing the system connection systematically. Let's explain the concept of the route control by using an example distribution system shown in Fig.8.

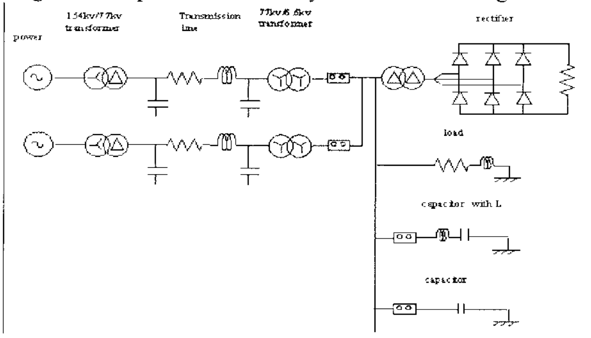


Fig. 8 Example distribution system

In the figure, power at a receiving side is supplied by one of two aerial transmission lines, which are connected to the utility power sources defined by constant voltage sources. At a receiving side there are harmonic source, load, and phase modifiers. The harmonic source is constructed by 6-pulse rectifier circuit. Two kinds of phase modifiers are considered, that is the shunt capacitor improving the power factor of load and is the shunt capacitor with 6% reactor. In the situation that the receiving power is supplied by the above transmission line, and shunt capacitor is connected, the harmonic flows from the rectifier to upper network and load because of the impedance resonance between the transmission line and the shunt capacitor. If the transmission route is changed from the above line to the below line, then the resonance of impedance is vanished so that the harmonic flow is reduced. Another way to reduce the harmonic flow is to change the phase modifier from the shunt capacitor to the shunt capacitor with 6% reactor.

The "route control" is, roughly speaking, to reduce harmonic flow by changing power network impedance using switching transmission routes and/or phase modifiers which include active filters.

3.3 Modeling and Harmonic Suppression for Distribution Systems[6]

In order to suppress the harmonic enlargement, a control strategy and a site location of shunt active filter were proposed. In their method, a shunt active filter operating as a parallel resistance for harmonic voltages and currents is installed at the end point of a power distribution line. This method, however, causes an undesired case in which the harmonics are magnified by an operation of the active filter.

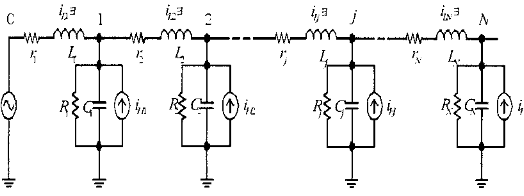


Fig. 9 A power distribution blanch

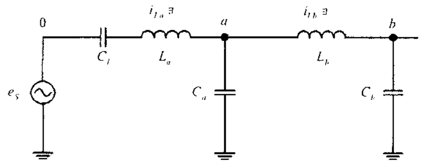


Fig. 10 A reduced order model of a power distribution blanch

Fig.9 shows a power distribution blanch. This is composed of a lot of LCR networks and has large amount of LC resonant frequency. The behavior of harmonic enlargement at one resonant frequency differs from that at other resonant frequency. Then, harmonic enlargement should be analyzed and suppressed at every resonant frequency. In the practical system, the dominant resonances occur below 1kHz, because the line resistances $r_1 \sim r_N$ dump the LC resonances. Then, a power distribution blanch can be represented by a reduced order model by using the modal analysis. Below 1kHz (to be precise, below the 3rd resonant frequency of Fig.9), the properties of i_{L1}/e_s and i_{Lj}/e_s in Fig.9 coincide to those of i_{La}/e_s and i_{Lb}/e_s in Fig. 10, respectively.

Fig.11 shows the proposed harmonic suppression strategy in which a series active filter is installed in parallel with the supply voltage e_s and it controls the line currents i_{L1} and i_{Lj}. Since it is clear that the properties of i_{La}/e_{AF} and i_{Lj}/e_{AF} coincide to i_{La}/e_s and i_{Lb}/e_s in Fig.10, respectively. As a result, the dominant resonances can be suppressed.

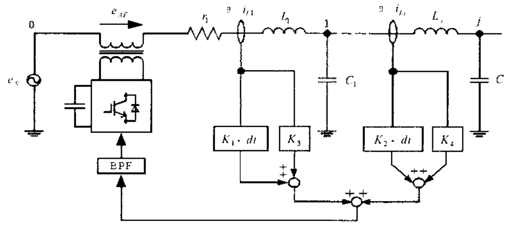


Fig. 11 A harmonic suppression strategy for a power distribution blanch

5. Conclusions

In this paper, the various suppression controls of harmonics in power system are proposed. The synchronized measurement system is the basic technology which enables to achieve these new control technologies for harmonics in distribution system.

The authors would like to express their gratitude for the financial supports of a program entitled "Research for the Future" of Japan Society for the Promotion of Science.

References

[1] T.Ohnishi et al, "Ac Line Voltage Harmonics Compensator With Excessive Current Control", IEEE Trans. on IEEE IES, vol.50, no.6, 2003.

[2] T.Takeshita, N.Matsui "Control of Active Filters Using Source Current Detection," Proc. of IEEE IECON'03, 2003, pp.1515-1520.

[3] S. Hamasaki and A. Kawamura, "Experimental Verification of Disturbance Observer based Line Current Detection type Active Filter for Load Resonance Suppression", IECON'02, Sevilla, Spain, SF-005139, 2002.

[4] H.Ukai, K.Nakamura, and N.Matsui, "DSP and GPS Based Synchronized Measurement System of Harmonics in Wide Area Distribution System", IEEE Trans. on IEEE IES, vol.50, no.6, 2003.

[5] H, Ukai, et al., "Suppression Control of Harmonics by Switching Route Connection in Distribution System", Proc. of IEEE IECON'03, 2003

[6] M.Saitou, T.Takeshita and N.Matsui, "Modeling and harmonic suppression for power distribution systems." *IEEE Trans on Indus. Elect.*, Vol.50, No.6, Dec, 2003.