Examination for Experimental Verification of Improvement of Power Quality in Distribution System by PCS

Shoji Kawasaki¹, Naohiro Terada² and Hisao Taoka²

1. School of Science and Technology, Meiji University, Kanagawa 214-8571, Japan

2. Power System Research Lab and Department of Engineering Electrical and Electronics Engineering, University of Fukui, Fukui 910-8507, Japan

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Abstract: In the future, the power quality will decrease by the introduction of a lot of renewable energy sources. The topic of this research is a new method of operation of PCS (power conditioning systems) in the future distribution system. The purpose of this research is development of PCS with a function of improvement of the distribution system. Therefore, the authors propose a method of the power quality improvement of the distribution system by PCS. In addition, the authors construct the control logic to use in PCS. The control logic suggests adding harmonic restraint function to conventional control. These were verified by simulation and an experiment. As the results, we confirmed that basic operation of PCS being carried out, harmonics were restrained, and power quality had improved.

Key words: Distributed generator, harmonics, voltage total harmonics distortion, power conditioner system, photovoltaic generation, power quality.

1. Introduction

In recent years, expectation of an environmental load reduction effect, and, for a breakaway from fossil energy resources dependence such as the oil, the number of DG (distributed generation) using renewable energy sources such as PV (photovoltaic) generation system and wind power generation system that connects to a distribution system has been increasing to reduce the influence on the environment in Japan. It is expected that supplying 5%-10% of primary energy demand by 2050 [1]. In addition, the non-linear load such as an air-conditioner or the LED light is increasing by the development of the power electronics technology. Those cause bad effects on

power quality of the distribution system. For example, the photovoltaic power generation depends on the weather, so the output is unstable. Therefore, deterioration of voltage imbalance and current imbalance or the increase of harmonics is worried in the distribution system. Nonlinear loads such as the inverter equipment are diversifying and these have a possibility of a bad influence on the distribution system. For example, these generate harmonics and are a cause to let the voltage distort. Harmonics is one of the causes of the malfunction of the electric equipment. In fact, an accident happened in Japan in the past. From the above, it is necessary to keep reliability of power and power quality. So far, the authors pay attention to the harmonics and had studied the influence which harmonics generated from DGs has on harmonics of distribution network [2] and determination method for optimal installation of AF (active filter) in distribution

Corresponding author: Shoji Kawasaki, assistant professor, research fields: optimization of distribution network configuration, and improvement of power quality. E-mail: kawasaki@meiji.ac.jp.

In this paper, the purpose of this research is development of PCS with a function of improvement of the distribution system. Therefore, the authors propose the control logic of PCS has a function of improvement of the distribution system. Moreover, in order to verify about the proposal control logic, the numerical calculation and experiment are carried out.

2.1 Outline of Using PCS

2.2 Outline of Control Logic

Harmonics command signal part:

Procedure 2: These sources are transformed into d-q axis. In addition, these data pass the filter of extract harmonics. As a result, harmonics component is extracted from these data.

Procedure 3: Multiply harmonics componental of

Fig. 1 PCS model.

terminal voltage by filter gain K_v . As a result, harmonics command signal is decided. The d-q axis transformer is used the Hilbert transformation [6].

There are two reasons to apply the Hilbert transformation. First, the d-q transformer is difficult by the single-phase alternating current circuit, but is enabled by using it. Second, the control is high-speed because d-q transformer becomes available. In addition, it becomes easy to change control logic. Thus, we can let you do movement same as AF in PCS.

Procedure 3: Inverter direct voltage source (ed) is obtained from voltage transformer. In addition, it is compared with reference voltage (ed^*), and error is processed through PI controller to maintain the inverter DC bus voltage consistency. As a result,

fundamental command signal is decided.

Procedure 4: These data are transformed into inverse d-q axis. (I_a^* , I_b^*).

Finally, all signals are summed, and PWM control is given it.

Determination logic of filter gain part:

Filter gain is necessary to give PCS improvement of a function of improvement of the distribution system.

As a result for that voltage sources becomes a harmonics compensation current instruction value by giving filter gain value k to harmonics voltage information [7]. That is, it is because filter gain value k can treat as $1/k$ (Ω), so it can do with a current instruction value by giving filter gain value k to a terminal voltage harmonics command signal. The filtering operation of PCS with a harmonics restraint function of this research turns into operation equivalent to the parallel type active filter by a voltage detection system.

Next, determination logic of filter gain is explained. From the voltage of interconnected point, THD (total harmonics distortion) is calculated and a filter gain value is adjusted with PI control as compared with the set-up desired value. Next, a filter gain value is adjusted so that capacity may not be exceeded by PI control, comparing the output current i_c with the current capacity I_{max} . And it is thought by choosing the smaller one from two filter gain values that the harmonics restraint effect according to PV output is acquired without exceeding surplus capacity. From the above, it is likely that power quality improvement function is added to conventional PCS.

3. Simulation Condition

3.1 Outline of Improvement Method of Power Quality

The outline of the proposed improvement method of power quality is shown in Fig. 3. We explain past research contents. The proposal method restrains the voltage THD in the distribution system by utilizing PCSs of DG as AF, moreover the voltage imbalance factor by controlling interconnected power factor of PCSs. At this time, the voltage THD of the distribution

system is controlled below on the environmental target level of Japan. Since the harmonics vary instantaneously in a distribution system, the harmonics are restrained in real time by obtaining the magnitude of voltages at each point from a number of IT switches' data.

In this research, improved only harmonics problem, but, in a figure, not only it but voltage problem such as imbalance voltage or voltage deviation is settled in the future.

3.2 Analytical Model of Distribution System

Using an analytical model is shown in Fig. 4. This model took Japanese various investigation studies into account [8]. This feeder is connected to 8 nodes of the analytical model. The line length between nodes is 0.5 km (total line length is 4.0 km), and each line is assumed the aluminum wire (AL-OE120).

Moreover, this feeder is connected to 8 loads 8 pole transformers, and 8 PV systems. Using load assumes downtown load. 100 V or 200 V load is connected to secondary voltage of transformer, and total load capacity is 2 MW. Total PV output is 30% of total

Fig. 3 Proposed improvement method of power quality.

Fig. 4 Analytical model of distribution system.

distribution load capacity. The model that assumes there is voltage distortion in the distribution system and case of output current distortion from non linear load. THD is obtained from voltage sources of each node in the distribution system and resistant the harmonics of distribution system by filtering operation of PCS. An analysis object is 5th and 7th harmonics. Because it is generally influenced by these. In addition, in order to verify that surplus capacity of PCS is available effectively, assume two cases. Because the output of PV is big, as for the daytime time, assume surplus capacity about 10%. Contrary to this, morning or evening time, assume surplus capacity about 60%. In addition, maximum THD of before resistant is 5.10% at node 8.

From the voltage information on two or more interconnected points, the maximum of THD in a distribution system is computed, a filter gain value is determined that the value is controlled to a control desired value, the harmonics of a distribution system are controlled, and THD is controlled. Although the output of PCS changes by changing a filter gain value at this time, since surplus capacity is used, compensation capacity applies compensation restrictions to a filter gain value so that surplus capacity may not be exceeded. The management desired value of THD of a distribution system is 5% of a harmonics level of environmental achievement of the power distribution system of our country [7]. The analytical model deviates from management desired value. Therefore, it is necessary to restraint harmonics of distribution system.

Moreover, the formula of THD is shown below.

$$THD = \left(\frac{\sqrt{\sum_{m=2}^M V_{n,m}^2}}{V_{n,1}} \times 100 \right)$$

THD [%]: voltage total harmonics distortion;

$V_{n,1}$: fundamental wave voltage at node n ;

$V_{n,m}$: m -th harmonics voltage at node n .

4. Verification of Harmonic Restraint Effect by Filtering Operation of PCS

4.1 Outline of Verification

This verification assumes two cases. In the case of two which we set up to node 7 and 8 in the case of one which we set up to node 8. Because of it has been reported that a high effect is acquired by controlling the installation part of PCS at the end [9]. The FFT analysis object is phase voltage of node 2,4,6,8. The improvement targeted value is 4%. The simulation software to use is PSIM.

4.2 Verification of Harmonics Wave

The FFT analysis results of the voltage wave in one PCS are shown in Figs. 5 and 6. The FFT analysis results of the voltage wave in two PCS are shown in Figs. 7 and 8. From a result, it seems that the restrained effect of 7th harmonics is small, and in any case, harmonics component is restrained all. It is thought that there are two causes. First, a set point of filter for the harmonics detection is lacking in adjustment. Second, filter gain has become the small value for 7th harmonics which is small in comparison with 5th harmonics.

(a) Surplus capacity 10%

(b) Surplus capacity 60%

Fig. 5 Restraint effect by one PCS (5th harmonic voltage).

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(a) Surplus capacity 10%

(b) Surplus capacity 60%

Fig. 6 Restraint effect by one PCS (7th harmonic voltage).

(a) Surplus capacity 10%

(b) Surplus capacity 60%

Fig. 7 Restraint effect by two PCS (5th harmonic voltage).

A voltage wave when an effect is the highest is shown in Fig. 9. It is few change, but voltage wave is improved.

Results of one PCS are shown in Table 1. Results of two PCS are shown in Table 2. In the case of 60%, it is confirmed that max THD is restrained in the case of either. However, in the case of 10%, it is not confirmed

(a) Surplus capacity 10%

(b) Surplus capacity 60%

Fig. 8 Restraint effect by two PCS (7th harmonic voltage).

Fig. 9 Voltage wave when an effect is the highest.

Table 1 Use capacity and max THD in one PCS.

PCS node8	Use capacity (%)	Max THD (%)
Surplus capacity (10%)	10	4.83
Surplus capacity (60%)	57	3.99

Table 2 Use capacity and max THD in two PCS.

PCS node8_7	Use capacity (%)	Max THD (%)
Surplus capacity (10%)	10	4.66
Surplus capacity (60%)	30	3.97

that max THD is restrained in the case of either. When surplus capacity is 10%, the desired value which the rise of the filter gain was suppressed by capacity restrictions and set up was not able to restrain. As for the result of the restrain THD effect is confirmed that a case in node 7 and node 8 is higher than a case only for node 8. It also confirmed that it is good to cooperate, and to operate plural PCS.

4.3 Verification of Fundamental Wave

FFT analysis results of fundamental wave are shown in Fig. 10. THD is calculated by the ratio of fundamental wave and harmonics wave. In other words, there is a possibility that THD is restrained without restraining harmonics. It clearly be seen that fundamental wave components don't change in Fig. 10. From all results, it seems that confirmed that THD restraint by filtering operation of proposal PCS.

5. Outline of Experiment

5.1 Outline of Control Logic for Experiment

PCS is single-phase at time of simulation. However, PCS is three-phase at time of experiment. The single-phase d-q transformer is generally said to be difficult [10]. In contrast, it is well known that the theory of three-phase d-q transformer is easy. Therefore, the application of the proposed control logic is easy. In addition, it seems that it is a merit that proposal logic is added easily to existing control logic.

5.2 Condition of Experiment

In order to verify the validity control system which was built by this research, the analysis model as shown in Fig. 11 was created using the actual inverter. The program was made by programming Language C. The specification of an experiment condition is described in Table 3. THD of the load is set high, owing to make intelligible a result.

5.3 Results of Experiment

Result of experiment is shown in Fig. 12.

(a) Surplus capacity 10%

(b) Surplus capacity 60%

Fig. 10 FFT analysis results of fundamental wave.

Fig. 11 Experimental apparatus.

Table 3 PCS. experiment condition.

Power supply	Line voltage	110 (V)
	Frequency	60 (Hz)
Load	Capacity	1.0 (kW)
	THD	20%
PCS (voltage type inverter)	Rate capacity (AC 200 V)	9.1 (kVA)
	Rated current	AC 26.3 (A)
	Voltage range	AC 0~230 (V)

From the results, it clearly be seen that voltage wave improved. However, with a distortion being big, the big effect was not provided because experimental apparatus was insufficient.

Fig. 12 Result of experiment waveform.

6. Conclusions

The purpose of this research is the development of PCS with a function of improvement of the distribution system. Therefore, the authors propose the new control logic of PCS. Proposal control logic has improvement harmonics in distribution system. Proposal control logic has improvement of harmonics in distribution system. Cost is lower than AF, and Proposal PCS can change the control logic easily and can easily install it. Moreover, in order to verify about the proposal control logic, the numerical calculation and experiment are carried out. From the results, it also confirmed that power quality was improved by proposal control logic and PCSs. Thus, it is suspected that proposal contents are reasonable.

The author thinks about future works, the validity of the PCS model and control system will connect to distribution system, and suggesting a logic for the voltage problem.

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