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배전계통에서 수동필터를 이용한 고조파 저감에 관한 연구

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A Study of Reducing Harmonics using Passive Filter in Distribution System

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Abstract - Recently, harmonic distortion becomes a very important problem of power quality in distribution system. This paper discusses the procedure of passive filter design, and presents the harmonic study of reducing harmonic distortion in distribution system using passive filters.

1. Introduction

A harmonic distortion is caused by nonlinear elements in the power system. The harmonics can cause a variety of problems in distribution system. Nowadays, harmonic distortion becomes a very important problem of power quality. More and more people are interest in how to reducing harmonic distortion in distribution system.

This paper illuminates harmonic distortion calculation and procedure of passive filter design. In this paper, a 3-phase full wave converter is used as a harmonic source in the simulation of this paper. And a passive filter control model is designed for control the passive filter bank.

The simulations of this paper are realized using ATPDraw program, which is a graphical preprocessor to the ATP version of the Electromagnetic Transients Program (EMTP).

2. Harmonic analysis

2.1 Harmonic in distribution system

The voltage and current waveforms in ac power circuits are expected to be sinusoidal, with constant amplitude and frequency, in Korea the frequency of distribution system is 60 Hz. However, the harmonic distortions into the distribution system causing the voltage and current waveforms to deviate from their intended sinusoidal form.

Under the assumption of a constant waveform distortion, the voltages and currents may be decomposed into a set of sinusoidal waveforms of varying amplitude and phase, with frequencies that are integer multiples of the fundamental frequency. In Fourier analysis, the frequency multiples of the fundamental are termed harmonic frequencies[1].

2.2 Harmonic distortion calculation

The voltage and current of harmonic component can be calculated using DFT method. The equation of DFT method as follows[1]:

$$V_k = \frac{1}{N}\sum_{n=0}^{N-1} v[t]e^{-jkn2\pi/N} \ (k=1,2,...,N-1) \tag{1}$$

$$I_k = \frac{1}{N}\sum_{n=0}^{N-1} i[t]e^{-jkn2\pi/N} \ (k=1,2,...,N-1) \tag{2}$$

where k is the number of harmonic order, N is the number of samples.

There are several measures commonly used for indicating the harmonic content of a waveform with a single number. One of the most common is THD, which can be calculated for either voltage or current[2]:

$$THD = \frac{\sqrt{\sum_{h=2}^{h_{\max}} M_h^2}}{M_1} \tag{3}$$

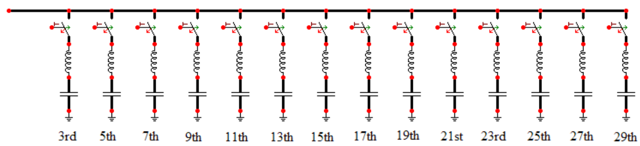
where M_h is the rms value of harmonic component h of the quantity M. THD is a measure of the effective value of the harmonic components of a distorted waveform. That is, the potential heating value of the harmonics relative to the fundamental.

2.3 Passive filter bank design

The Passive filters are composed by inductance, capacitance, and resistance elements. They are relatively inexpensive compared with other means for eliminating harmonic distortion[2][3].

They are employed either to shunt the harmonic currents off the line or to block their flow between parts of the system by tuning the elements to create a resonance at a selected harmonic frequency.

The most common type of passive filter is the single-tuned passive filter. It is the most economical type and is commonly sufficient for the application in distribution system.



<Fig. 1> Passive filter bank modeing in distribution system

A passive filter bank modeling is designed to reducing the harmonic distortion of distribution system as shown in Fig. 1.

The passive filter bank can be controlled by a passive filter controller. The passive filter controller can calculates the harmonic components using DFT. And compare the calculated values with the limit values of harmonic components from 3 to 29 harmonic order. If the calculated value is greater than the limit value in any odd harmonic, the controller will drive a switch to connect the passive filter with distribution system for reducing harmonic distortion. For example, if calculated value of 5th harmonic component is greater than the limit value, the 5 harmonic filter will be connected to system by switch closing. This design can decrease the power consumption of passive filters.

There are two steps to design passive filter. The procedure of passive filter design as follows[3]:

Step 1: calculate the capacitor reactance X_C. The capacitor reactance may be obtained from the following relation:

$$X_C = \left(\frac{h^2}{h^2-1}\right)X_{eff} \tag{4}$$

where

$$X_{eff} = \frac{kV_{LLsys}^2}{Q_{eff}(Mvar)} \tag{5}$$

Step 2: The inductive reactance can be calculated using the equation as follows

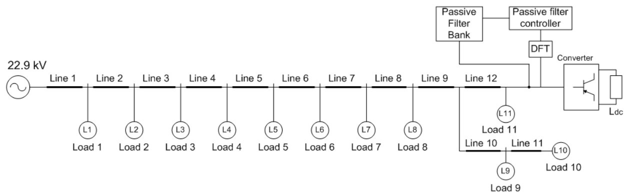
$$X_L = \frac{X_C}{h^2} \quad (6)$$

where X_{eff} is the effective reactance of the passive filter. Q_{eff} is the effective reactive power (Mvar) of the passive filter. V_{LLsys} is the nominal system line-to-line voltage. X_C and X_L is the capacitive reactance and inductive reactance of the passive filter, h is the harmonic number to which the filter is tuned.

3. Simulation

3.1 Distribution system modeling

A distribution system is designed as show in Fig. 2. The source of this system is a 3-phase 22.9 kV. There are 12 bus and 11 linear loads in this system. The line parameters of the distribution are lised in Table 1.



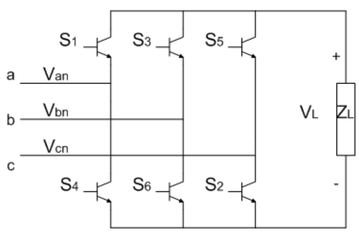
<Fig. 2> One line diagram of distribution system

Fig. 2 shows the passive filter bank modeling is connected with distribution system at point of common coupling to reducing harmonic current in this simulation.

<Table 1> Line parameters of system

Bus	Length [km]	Positive sequence impedance [Ω]	Zero sequence impedance [Ω]
Line 1	1.016	0.0882995+j0.096957	0.1126734+j0.065744
Line 2	0.990	0.1804770+j0.386150	0.4507767+j1.186980
Line 3	0.711	0.1296153+j0.277326	0.3237396+j0.852468
Line 4	0.195	0.0944128+j0.076060	0.1631391+j0.261099
Line 5	0.565	0.1029995+j0.220378	0.2572615+j0.677418
Line 6	0.602	0.1097446+j0.234810	0.2741087+j0.721780
Line 7	0.325	0.1573546+j0.140837	0.2718986+j0.435165
Line 8	0.634	0.1162116+j0.247293	0.2836845+j0.770728
Line 9	0.875	0.1603866+j0.341296	0.3915205+j1.063703
Line 10	0.786	0.1440730+j0.306581	0.3516973+j0.955509
Line 11	0.039	0.0113524+j0.006073	0.0145793+j0.004032
Line 12	1.593	0.2919953+j0.621353	0.7127910+j1.936546

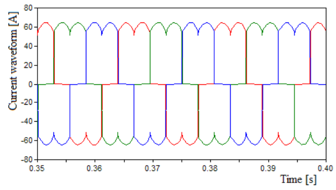
A 3-phase full wave converter is used as harmonic source into the system. The converter is triggered at an angle $\alpha = 60^\circ$. This angle is measured from the time the phase voltage is equal to zero. The impedance of load connect with converter dc output side is 500 Ω. Fig. 3 shows the equivalent circuit of 3-phase full wave converter[4].



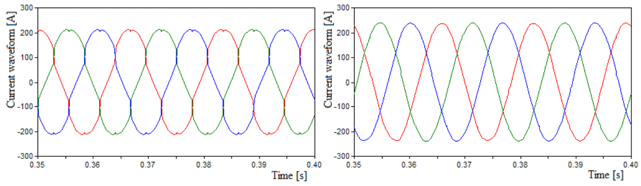
<Fig. 3> Equivalent circuit of 3-phase full wave converter

3.2 Results

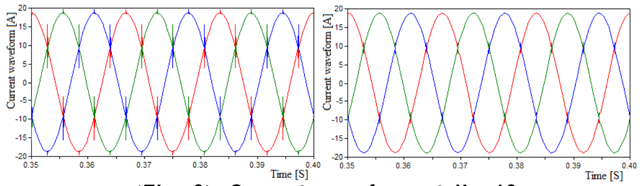
When the passive filter bank connected with distribution system, the harmonic current of system will be reduced by the passive filter bank. Fig. 4 shows the current waveform of converter ac input side in distribution system. Fig. 5 and 6 show the current waveforms before and after filtering harmonics at line 4 and line 10.



<Fig. 4> Current waveform at converter ac input side



<Fig. 5> Current waveform at line4



<Fig. 6> Current waveform at line10

Table 2 shows the THD of harmonic current before and after the passive filter bank connect with distribution system.

<Table 2> THD of harmonic current in simulations [%]

Line	A phase		B phase		C phase	
	before	after	before	after	before	after
Line 1	8.1348	0.7295	8.1635	0.3274	8.1473	0.7431
Line 2	8.6456	0.7693	8.6737	0.3434	8.6566	0.7823
Line 3	8.8235	0.7829	8.8516	0.3490	8.8342	0.7958
Line 4	9.2435	0.8146	9.2711	0.3622	9.253	0.8275
Line 5	10.284	0.8905	10.31	0.3942	10.29	0.9035
Line 6	10.662	0.9170	10.688	0.4058	10.668	0.9304
Line 7	11.191	0.9533	11.217	0.4220	11.196	0.9675
Line 8	12.185	1.0185	12.21	0.4518	12.187	1.0348
Line 9	14.255	1.1429	14.279	0.5120	14.251	1.1657
Line 10	1.7195	0.2235	1.7177	0.2509	1.7011	0.2337
Line 11	1.7244	0.2222	1.7226	0.2496	1.706	0.2325
Line 12	16.531	1.2626	16.553	0.5756	16.521	1.2959

4. Conclusion

The passive filter bank can sufficient eliminate harmonics. The passive filter controller can shut off the unused filters of passive filter bank to decrease the reactive loads, which are connected with distribution system. This method can control the reactive loads of passive filters in a minimum value, to decrease the power consumption of passive filters. The line current flow into this system also can be decreased.

Acknowledge

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[참 고 문 헌]

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