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Control Strategy For Active Power Filter Based On P-Q Theory Under Non-Ideal Mains Voltages

Abstract— Harmonics on the electrical system is a disturbance that causes the waveform of currents and or voltages are distorted. Mitigation of harmonics needed to reduce the negative impacts. Active power filter (APF) is one method to reduce harmonic waves, which injects the opposite waveform with harmonic wave. P-Q Theory is used to calculate the reference current to compensate harmonics. But, P-Q Theory has weakness if applied under non- ideal mains voltage. Phase Lock Loop (PLL) is used to normalization the non-ideal main voltage before calculate the reference current. Based on the results of simulation and analysis show the effectiveness of the control strategy being used.

Keywords— harmonic; P-Q Theory; active power filter; non- ideal mains voltages.

I. INTRODUCTION

The development of power electronics that is used as an interface between the load and electrical system effect on power quality, especially the emergence of electrical harmonics [1],[2]. Harmonic currents generated by non-linear loads such as rectifiers, variable speed drive, and others. These harmonic currents will affect the quality of the electrical power distribution system and the performance of electrical equipment [3].

Passive filter is one method that used to reduce harmonic currents. These passive filters use a combination of inductors and capacitors to eliminate the harmonics frequency that have been determined. The weakness of passive filters are only able to eliminate the harmonics frequency that have been determined, so it can not eliminate the harmonics frequency than those specified. Active filters have advantages can eliminate various harmonics frequency that arise. In active filter, there are voltage source inverter (VSI) and controllers to regulate the compensation current that given to eliminate harmonic currents that arise [4],[5].

In a real implementation, the waveform of the voltage source is often not in a pure sinusoidal condition [6],[7]. so that the signal voltage to be used in the calculation of active filter needs to be normalized. This condition is also called non- ideal main voltage.

p-q theory is one of the reference current generation methods to determine the anti-harmonic current waveform.

This p-q theory has the advantage of fast response compared to other methods [8],[9]. but the P-Q Theory has a disadvantage when applied under non-ideal main voltages. the performance of the P-Q Theory goes down under non-ideal main voltages. this causes compensation of active filter harmonics controlled by P-Q Theory is not optimal [10],[11]. in this paper, the P-Q Theory calculation is improved in generating reference currents in the harmonic active filter, so the accuracy of the P-Q Theory calculation is not affected by the source voltage waveform

II. MODELING OF ACTIVE POWER FILTER

Active filter serves to eliminate harmonics at the source based on the control system used. In addition, the active filter also serves to compensate for reactive power to the load [12]. Figure 1 shows configuration of active power filter connected to non-linier load.

The active power filter circuit configuration consists of three main parts: a 1 voltage source inverter (VSI) with a capacitor on the DC side, a control circuit, and a switching ripple filter. VSI is a three phase inverter with three switch arms; the control circuit is a digital signal processor (DSP).

And the ripple switch is an inductor that is series on each phase on the AC voltage side of the inverter. Figure 1 2 shows a block diagram of a shunt active power filter.

Nonlinier load

PCC

Figure 1. active power filter

The main purpose of the 1 shunt active power filter is to compensate for harmonic currents due to non-linear load να 2

−1

F1

2

−1

1 va

2

currents iL that propagate to the source current is. Harmonics

$[v\beta] = \sqrt{\quad} I$

I [vb]

(5)

compensation current ic will eliminate the harmonic current in the source current

3 I √3

[0 2

√3I vc

2]

is so that it becomes sinusoidal. The

harmonic compensation current is obtained by generating a reference current ic * which is

a signal waveform from the

iα 2 F1

−1 −1

1 ia

2 2

harmonic component current [13].

$[i] = \sqrt{\ } I$

I [ib]

(6)

β 3 I √3

0

√3I ic

III. IDEAL AND NON-IDEAL MAIN VOLTAGES

Before Mains voltage waveform is very influential in the generation of reference current. so it will also affect the compensation of harmonics. Ideal voltage is purely sinusoidal voltage while the non-ideal voltage is distorted or unbalanced

[2 2]

p v_{α} v_{β} i_{α}

$[q] = [-v_{\beta}\ v_{\alpha}]\ [i_{\beta}]$

voltage [14],[15]. Ideal voltage as shown in equation (1).

p P ~p

(7)

va $\sin(\omega t)$

$[q] = [q \sim q\ ]$

$[vb] = Vrms\sqrt{2}\ [\sin(\omega t - 120o)]$

(1)

Equation of current source as a function of the power p

$v_c \sin(\omega t + 120^o)$

and q are:

iα 1

$v\alpha$ -$v\beta$ p

Unbalance voltage is a three-phase voltage which has a large amplitude and the phase shift is not same. Unbalance voltage can be expressed in 3 positive and negative sequence as [iβ] = vα2+ vβ 2 [vβ vα] [q]

(8)

in equation (2).

vau [vbu vcu

vau+

] = [vbu+

vcu+

vau-

] + [vbu-]

vcu-

(2)

From equation (7) and equation (8) can be seen that to

eliminate reactive power from the source is to make q variable be negative in equation (9).

To separate the harmonic components of current sources, by using only the AC components in p power. So that the reference current is raised is:

Equation (2) describes the unbalanced voltage is the sum of the positive sequence component Vau+, Vbu+, Vcu+, and negative sequence components Vau-, Vbu-, Vcu-, Voltage distortion often found in electrical distribution iα-c* 1

[iβ-c*] = v + v

$v\alpha$ -$v\beta$ p~ − PLoss

[$v\beta$ $v\alpha$] [-q]

(9)

systems. Voltage distortion basically occurs when there is a harmonic component on the fundamental voltages component. distorted voltage can be expressed as the equation (3).

Reference current in equation (9) is then transformed into abc frames with equation (10) below:

1 0

i F−1 √3 1

v v v

a-c*

iα-c*

ad af ah

[ib-c*] = √3 I 2

2 I [i]

(10)

[vbd] = [vbf] + [vbh]

(3)

ic-c*

$|-1 - \sqrt{3}|$

β-c*

vcd vcf vch

[2 2]

The voltages Vaf, Vbf, and Vcf are fundamental components in each phase. The voltages Vah, Vbh, and Vch are the harmonic components which can consist of several frequency levels

IV. REFERENCE CURRENT BASED ON P-Q THEORY Compensation current waveform is determined by the

reference current waveform. Reference current compared with the anti harmonic current injected by using hysteresis current control. Then, the switching pattern will be obtained to switch the VSI [16],[17]. Reference current in this study were calculated using P-Q Theory . three-phase waveform of

V.

STRATEGY ON NON-IDEAL MAIN VOLTAGES Compensation current equation in equation (9) is

calculated by assuming the mains voltage in ideal conditions. But the condition is often found in industrial electrical systems, 3 the voltage waveform is often not ideal or not at sinusiodal conditions that would affect to generation of reference current waveform.

In this study, phase lock loop (PLL) is used to detect the phase (ωt) [18]. then three-phase voltage waveform that will be used in the calculation of the reference current generation is calculated by equation (11) below:

va sin(ωt)

voltages and currents in the abc frame will be transformed to be αβ frame using a Clarke transformation. Equation (4) and

$[v_b] = 220\sqrt{2}\,[\sin(\omega t - 120^o)]$

(11)

(5) respectively are voltage and current transformation matrix of abc coordinates into α-β coordinates.

vc sin(ωt + 120o)

Control system configuration 1 of active power filter under non-ideal main voltage as shown in Figure 2. The PI controller is used to make constant voltage on the DC side of VSI.

3 phase source Nonlinier Load

Figure 2. active power filter with P-Q Theory

VI. RESULT AND ANALYSIS

Active power filter configuration as shown in Figure 3 is simulated with Matlab / Simulink to determine the performance of the system. Time sampling is 0.000006 s. System specifications as shown in Table 1.

TABLE I. Active power filter parameter

Figure 4. THD of current source before compensated.

Figure 5. THD of current source after compensated Simulation results show the THD of current source before

compensated is 28.34% as shown in Figure 4. While after compensated, the THD current of source is 2.26% as shown in Figure 5.

B. Simulation for Non- ideal Main Voltage

Non-Ideal main voltages could be unbalance and or dirtorted voltage. The unbalanced voltage is formulated on the simulation as shown in the following equation (12).

va sin(ωt)

[vb] = 220√2 [sin(ωt − 120o)]

A. Simulation for Ideal Main Voltage

The voltage waveforms in ideal conditions is a pure sinusoidal. The applied voltage as in equation (11) with Vrms

$v_c \sin(\omega t + 120o) \sin(3\omega t)$

$+ 31.11 [\sin(3\omega t + 120o)]$

$\sin(3\omega t - 120o)$

(12)

= 220 volts. Figure 3 shows the results of testing under ideal conditions.

Non-linear load with 6-pulse rectifier will cause distortion of the current source waveform.

Total Harmonic Distortion (THD) at ideal voltage conditions as shown in Figure 4.

Figure 6 shows the simulation results in unbalanced voltage conditions. Negative sequence components cause the voltage to be non-ideal. Calculation of the reference current by P-Q Theory at unbalanced voltage conditions will cause the THD is relatively larger than at ideal main voltage. Figure 7 show the THD at unbalanced voltage conditions

400

0

-400

0

1

0

-1

0

1

0

-1

0

0.5

0

-0.5

0.02

0.04

0.06 0.08 0.1

400

0

-400

0

1

0

-1

0

1

0

-1

0

0.5

0

-0.5

0

0.02

0.02

0.04

0.04

0.06 0.08 0.1

0.06 0.08 0.1

0 0.02

0.04

0.06 0.08 0.1

Time(s)

Time(s)

Figure 6. simulation results at unbalanced main voltage.

Figure 3. simulation result under ideal voltage.

C. Simulation for normalizing non-ideal main voltage

Figure 10 shows the simulation results at distorted voltage with voltage normalization. THD of current source at distorted main voltage as shown in Figure 11

Figure 7. THD of current source after compensated at unbalanced main voltage.

Distorted main voltage at this simulation using the 3rd and 5th harmonic as at following equation (13). The simulation results at distorted main voltage shown in Figure 8. THD of current source at distorted main voltage shown in Figure 9.

400

0

-400

0

1

0

-1

0

1

0

-1

0

0.5

0

-0.5

0

0.02

0.02

0.02

0.02

0.04

0.04

0.04

0.04

0.06 0.08 0.1

0.06 0.08 0.1

0.06 0.08 0.1

0.06 0.08 0.1

va sin(ωt)

Time(s)

$[v_b] = 220\sqrt{2}\ [\sin(\omega t - 120o)]$

v_c $\sin(\omega t + 120o)$ $\sin(3\omega t)$

$+\ 31.11\ [\sin(3\omega t - 120o)]$

$\sin(3\omega t + 120o)$ $\sin(5\omega t)$

$+\ 24.89\ [\sin(5\omega t - 120o)]$

$\sin(5\omega t + 120o)$

(13)

Figure 10. The simulation results for normalization main voltage.

THD at distorted main voltage is relatively larger than at ideal main voltage. the THD of current source is 10.50% as shown in Figure 9.

400

0

-400

Figure 11. THD of current source for normalization main

voltage.

From the test results, the p-q theory can be more precise. The THD at non-ideal main voltages can be corrected from 10.50% to 2.69%.

0

1

0

-1

0

1

0

-1

0

0.5

0

-0.5

0

0.02

0.02

0.02

0.02

0.04

0.04

0.04

0.04

0.06 0.08 0.1

0.06 0.08 0.1

0.06 0.08 0.1

0.06 0.08 0.1

VII. CONCLUSION

In this study, strategy control 1 of active power filter coupled photovoltaic under non-ideal main voltage has been proposed. P-Q Theory is used to calculate the reference current, but this theory does not work accurately at under non- ideal main voltage, therefore, PLL is used to normalize the main voltage signal before calculate the reference current.

From the simulation results can be obtained main point as

Time(s)

Figure 8. simulation results at distorted main voltage.

Figure 9. THD of current source after compensated at distorted main voltage.

normalizing main voltage under non-ideal main voltage can increase the accuracy of P-Q Theory. The THD at non-ideal main voltages can be corrected from 10.50% to 2.69%. The result of THD were very close as in the ideal main voltage.

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