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ANALAYSIS OF ACTIVE POWER LINE CONDITIONER UNDER VOLTAGE UNBALANCE CONDITION USING ID-IQ THEORY AND CURRENT CONTROLLERD HYSTERESIS CONTROLLER

Sumit Kharbanda[1], **Utsav Sharma**[2]

Department of Electrical Engineering, PEC University of Technology

ABSTRACT

In recent years the active and hybrid power filters have emerged as the devices which can perform harmonic eliminations as well as other related problems such as harmonic distortion, flicker, inter-harmonics and interference etc. more effectively than the passive filters. The active power filters are used to filter out higher as well as lower order harmonics in the power system. This paper deals with the reference signal generation techniques namely p-q theory and id-iq theory and some of the controlling schemes of APF. The paper presents a brief study of active power filter (APF) implemented using id-iq power theory using hysteresis control strategy under non-sinusoidal and harmonically unbalanced systems.

Keywords*— *Active Power Filter (APF); Hysteresis Controller; id-iq theory; p-q theory

I. INTRODUCTION

With the emergence of sinusoidal voltage sources, the problem of efficiency of power system network came into existence. The power system network is more efficient if the load current is in phase with the source voltage. Thus, the concept of reactive power appeared which defines the quantity of electric power which is not in phase with the source voltage. The apparent power gives the idea of how much power can be delivered or consumed if the voltage and current are sinusoidal and perfectly in phase. The power factor gives a relation between the average power actually delivered or consumed and the apparent power at the same point. Thus, higher the power factor, the better the circuit utilization. For a long time power factor correction could be performed using capacitor banks, or reactors in some cases. Since the introduction of power electronics in late 1960s, nonlinear loads that consume nonsinusoidal current have increased significantly. An industrial application such as adjustable speed drives consume a lot of reactive power and thus lead to harmonics in the system. Hence, power system in some cases have to be analyzed under nonsinusoidal conditions leading to the development of the p-q and id-iq theories. The shunt active filter in a three phase system is one of the most fundamental active filter intended for harmonic-current compensation of a nonlinear load. The shunt active filter equipped with current control is to draw the compensating current i_C from the ac power source, so that it cancels the harmonic current contained in the load current i_L. A voltage-source PWM converter is generally considered the power circuit for the active filter instead of current-source PWM converter. [1]

II. INSTANTANEOUS POWER THEORIES

In this section two power theories are discussed. In section II-A instantaneous active and reactive power theory (p-q theory)is discussed and in section II-B instantaneous active and reactive current component theory (id-iq theory) is discussed in detail

2.1 P-Q Theory

The three instantaneous powers-the instantaneous zero sequence power, the instantaneous real power p, the instantaneous reactive power q—are defined from the instantaneous phase voltages and line currents on the αβ0 axes as:-

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \qquad (1)$$

The αβ0 transformation or Clarke`s transformation gives the relationship between the three-phase instantaneous voltages in the abc phases, into the instantaneous voltages on the αβ0-axes. The Clarke`s transformation matrix is given by:- [2]

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \qquad (3)$$

The two powers have an average part and an oscillating part. Thus, the two powers are separated into their average and oscillating components. The Active Power Line conditioner (APC) should compensate the oscillatory part so that the average power component remains in the mains. After eliminating the average power component the power to be compensated are obtained. The compensation currents are obtained by inverting the matrix (1). These currents are obtained as:-

$$\begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix} = \frac{1}{{v_\alpha}^2 + {v_\beta}^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p_c \\ q_c \end{bmatrix}$$

(4)

$$\begin{bmatrix} ic_a \\ ic_b \\ ic_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}^T \begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix}$$

(5)

2.2 id-iq theory

The mains voltage $V_{\alpha\beta0}$ and load current $I_{\alpha\beta0}$ are obtained using Clark`s transformation matrices (2) and (3) from V_{abc} and I_{abc} respectively. Then, the currents I_d and I_q are obtained from $I_\alpha$and I_β as:-

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

(6)

Where,

$$\cos\theta = \frac{-V_\beta}{\sqrt{{V_\alpha}^2 + {V_\beta}^2}}$$

$$\sin\theta = \frac{V_\alpha}{\sqrt{{V_\alpha}^2 + {V_\beta}^2}}$$

(7)

$i_d = I_d + \tilde{i}_d$ and $i_q = I_q + \tilde{i}_q$. Extracting the oscillating components from both $i_d - i_q$ and obtain reference current $ic_d - ic_q$ to be compensated such that $ic_d = -\tilde{i}_d$ and $ic_q = -\tilde{i}_q$. Then we convert $ic_d - ic_q$ to $ic_\alpha - ic_\beta$ using:- [3]

$$\begin{bmatrix} ic_\alpha \\ ic_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}^{-1} \begin{bmatrix} ic_d \\ ic_q \end{bmatrix}$$

(8)

Then convert $ic_\alpha - ic_\beta$ to ic_{abc} using Inverse Clarks Transformation:-

$$\begin{bmatrix} ic_a \\ ic_b \\ ic_c \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix}$$

(9)

Feed the obtained reference current or compensating current and actual current to the hysteresis controller and switch the converter accordingly to feed the compensating current at the PCC (Point of Common Coupling).

III. CURRENT CONTROL TECHNIQUE

Hysteresis current controller

The Hysteresis current controller uses some type of hysteresis between the actual current and obtained reference current such that their difference always stays within the hysteresis band. The hysteresis band is designed in such a way that the error between the two currents is less than 5%.

When the actual current i_{abc} becomes greater than the reference current ic_{abc} by the hysteresis band then the PWM inverter leg is switched in the negative direction and when the actual current i_{abc} become less than the reference current ic_{abc} by the hysteresis band then the PWM inverter leg is switched in the positive direction.

$i_{abc} > (ic_{abc} +$ HB) lower switch is ON and upper switch is OFF

$i_{abc} < (ic_{abc} -$ HB) lower switch is OFF and upper switch is ON.

Where, HB= (0.05*ic_{abc}).[4]

IV. VOLTAGE AND CURRENT UNBALANCE

Voltage unbalance in a three-phase system is given by difference in the phase voltages, or when the phase difference is not 120°. Voltage unbalance in a three phase system is a condition when any one of the phase voltages is not within the acceptable limits of nominal voltage. There are several causes of voltage unbalance in the system:-

1. Unbalance three phase loading
2. Variation in single-phase loading causes the current in the three phase conductors to be different producing different voltage drops and thus causing the phase voltages to become unbalanced.
3. Blown fuses or overcurrent protective devices.
4. Fault in one of the phases.

Voltage Unbalance would cause a current unbalance in the system but the reverse is not necessarily true. The formula to calculate the current unbalance is:-

$$\frac{\max\left((I_m - I_a),(I_m - I_b),(I_m - I_c)\right) * 100\%}{I_m}$$

Where,

I_m is the mean of current in three phases i.e ($(I_a + I_b + I_c)/3)$

I_a is the current in phase a

I_b is the current in phase b

I_c is the current in phase c

The maximum allowable current imbalance in the system is 10%.[5]

V. SIMULATION ANALYSIS

Simulation of the system is done using MATLAB. The system parameters are given in the table. The non-linear load comprises of: - Single phase rectifier, Single phase voltage controller and 3 phase diode bridge rectifier feeding RL load. The simulation is given below:-

TABLE I.

S.No	Components
1	Source Inductance L_s=1μH
2	Coupling Inductance L_m=1mH
3	Source Voltage=325V (peak value)
4	DC link voltage:-750V

VI. RESULTS

TABLE II. UNBALANCE CONDITION:-

S.No	Load	T.H.D(%)
1	System of load:- Single phase rectifier, Single phase voltage controller and 3phase diode bridge rectifier feeding R=40Ω and L=1mH	Phase a:- 2.81% Phase b:-2.91% Phase c:- 2.00%

VII. HARMONIC ANALYSIS IN CASE OF UNBALANCED CONDITION

TABLE III. SOURCE CURRENT

Phase	Fundamental (A)	3rd	5th	7th	9th	11th
A	28.42	0.16	0.05	0.18	0.02	0.02
B	28.17	0.06	0.15	0.18	0.03	0.06
C	27.86	0.20	0.09	0.11	0.04	0.07

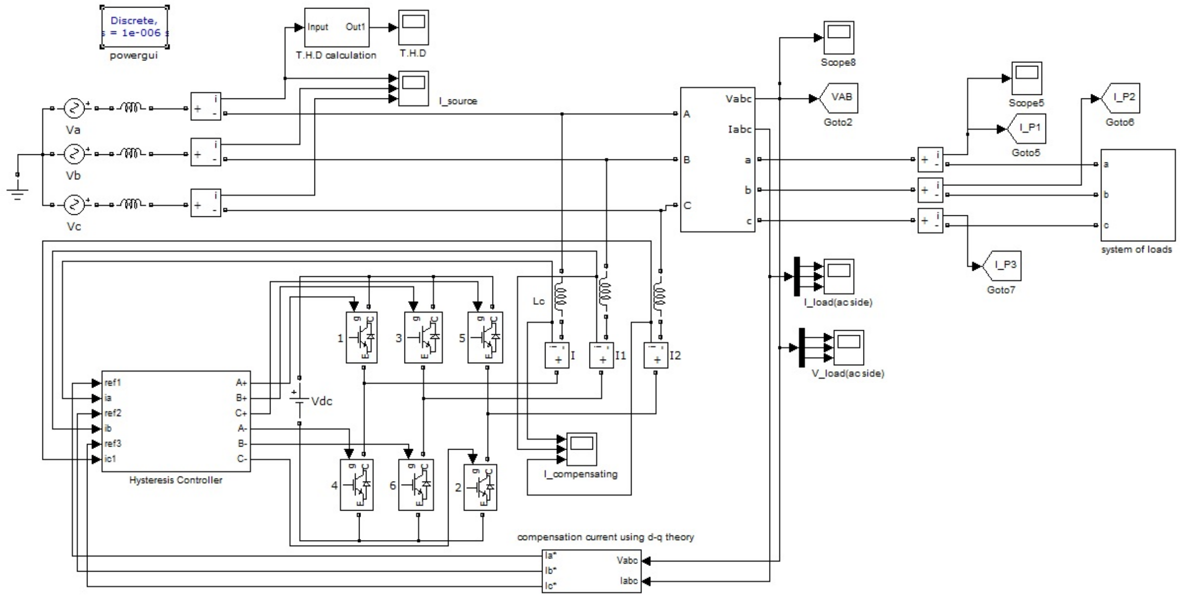
TABLE IV. COMPENSATING CURRENT

Phase	Fundamental (A)	3rd	5th	7th	9th	11th
A	11.23	3.50	4.42	2.54	0.99	0.48
B	11.72	4.80	2.46	3.15	0.89	0.98
C	12.66	1.53	2.76	1.26	0.34	1.12

TABLE V. LOAD CURRENT

Phase	Fundamental (A)	3rd	5th	7th	9th	11th
A	34.99	3.59	4.47	2.72	1.01	0.48
B	35.09	4.81	2.61	3.32	0.88	0.99
C	15.21	1.36	2.72	1.35	0.36	1.09

As shown in the table above the harmonic requirements of the load are met by the Active Power Line Conditioner and thus the harmonics drawn from the source are reduced to minimum possible.



VIII. CONCLUSION

The simulations results shows that after compensation using Active Power Filter the Total Harmonic Distortion is reduced to around 2% for a three phase system supplying non-linear load. The T.H.D for different phases is shown in table and from the results of Harmonic Analysis it can be seen that the harmonic requirement of the load is met by the compensator, hence the harmonics are not drawn from the source thus the source waveform becomes sinusoidal with current T.H.D of around 2%.

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