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BASIC OF REFRANCE CURRNT GENERATION AND CURRENT CONTROLLER FOR SHUNT COMPENSATOR

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Abstract

This paper is deal with the p-q theory for the generation of reference current in shunt current compensation and reference voltage in series voltage compensation, and different type of current controller. Basic p-q theory is use to generate reference current and voltage in shunt and series compensation respectively Clarke transformation i.e. α-β-0 transformation and inverse Clarke transformation is use in basic p-q theory. There are various current control methods proposed for shunt compensator but in terms of quick current controllability and easy implementation hysteresis band current control method has the highest rate among other current control methods such as sinusoidal PWM. The results are supported by detailed simulation studies on a three phase four-wire compensated system using Matlab.

INTRODUCTION

Harmonic disturbance in the power system are increased due to large use of power electronics devices. Nonlinear load are responsible for harmonic and reactive power. Harmonics causes problem in power system and in consumer product such as equipment overheating, capacitor blowing motor vibration, excessive neutral current and low power factor. In past passive LC filter and capacitor have been used to eliminate line current harmonics and to compensate reactive power by improving power factor but these filters have the limitation of large size, resonance and fixed compensations behavior due to this conventional solution become ineffective.

Due to the ineffectiveness of conventional solution the terms active power filter are come also called reactive power compensator. The first control system based on p-q theory is explain by akgi .konazawa and nabaeTheory related to instantaneous power broadly classified in two group first one is define the power on the αβ0 reference frame which is mainly based on the abc to αβ0 formation. Second type defines the power directly in the abc phase. In 1983 akgi .konazawa and nabaeintroduced the instantaneous active and reactive power theory which is also called "p-q theory,". p-q theory is mainly use for the generation of reference current of reactive power compensator, because it define the power clearly. In the p-q theory set of instantaneous powers are define in time domain therefor the behaviors of voltage and current are not restricted. This theory is applicable to three phase system with or without neutral conductor. This theory valid in both steady state and in transient state. This theory define the power clearly it consider the three phase system together not as a sum of three single phase circuit. p-q theory is commonly used in the power conditioner because it gives the very flexibility designing control strategies and implement in the controller.

There are different type of current controller but due the quick current controllability and easy implementation hysteresis band current control method is used largely

CONCEPT OF POWER IN THREE PHASE CIRCUIT

Due to generation of sinusoidal voltage at constant frequency alternating current (AC) transmission and distribution power system are develops at the end of 19^{th} century. Due to the sinusoidal voltage with constant frequency design of transformer transmission line distribution line are simplified. If the line voltage is not sinusoidal many problem are arrases in design of machines and generated electrification.

When load current is in phase with the source voltage the electric power could be more efficient, due to this the concept of reactive power arrases. Reactive power shows the quantity of electric power due to lagging or leading of load current with source voltage. In the one cycle average reactive power is zero. This means that the reactive power does not take part in energy transfer from source to the load. As soon as concept of reactive power are arrases the concept of apparent power and power factor were created. Apparent power shows the how many power delivered when voltage and current are sinusoidal and both source voltage and current are in phase. Power factor gives the idea about the actual power transfer and the apparent power at the some point. Therefore it is very important to maintain the power factor higher as possible as. Due to the higher power factor circuit become more efficient electrically and economically.

The current and voltage in the single phase circuit are express as follows where root mean square values of voltage & current are V and I are as follows.

$$Voltage\ V(t) = 1.4\,\mathrm{V}\sin(\omega t)$$

$$Current\ i(t) = 1.4 I sin(\omega t - \emptyset)$$

Instantaneous power is multiplication of the instantaneous voltage and current

$$\mathrm{p(t) = v(t)i(t)}$$

$$=2\mathrm{VIsin}(\omega t)\sin(\omega t - \emptyset) = \mathrm{VIcos}\emptyset[1 - \cos(2\omega t)] - \mathrm{VIsin}\emptyset\sin(2\omega t)$$

{PART – A} **{PART – B}**

{Part A}: has average value equal to $\mathrm{VIcos}\theta$ VIcosΦ which is also called the active power or real power

{Part B} : has average value is equal to zero which is also called reactive power or imaginary power from the above equation it is clear that the instantaneous power flow in the a single phase system is not unidirectional and has constant.

PHYSICAL MEANIG OF POWER IN THREE PHASE CIRCIT

Physical meaning of the instantaneous real, imaginary and zero sequence powers are explain in figure1

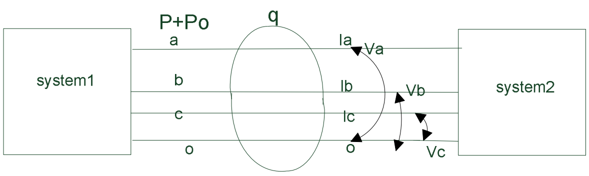


Figure1. Physical meaning of instantaneous power

$p + p_0 =$ Instantaneous total power flow per time unit

q= Total power flow between the phases without transferring power

The all three power has average and oscillating part

$$\text{Real power } p = \bar{p} + \tilde{p}$$

$$Reactive\ power\ q = \bar{q} + \tilde{q} \quad Zero\ sequnce\ power\ p_0 = \overline{p_0} - \tilde{p}_o$$

Average and oscillating part of active and reactive part can be expressed as

$$\bar{p} = 3v_+ I_+ \cos(\emptyset_{v+} - \emptyset_{i+}) + 3v_- I_- \cos(\emptyset_{v-} - \emptyset_{i-})$$

$$\bar{q} = 3v_+ I_+ \sin(\emptyset_{v+} - \emptyset_{i+}) - 3v_- I_- \cos(\emptyset_{v-} - \emptyset_{i-})$$

$$\tilde{p} = -3v_+ I_- \cos(2wt + \emptyset_{v+} - \emptyset_{i-}) - 3v_- I_+ \cos(2wt + \emptyset_{v-} - \emptyset_{i+})$$

$$\tilde{q} = -3v_+ I_- \sin(2wt + \emptyset_{v+} - \emptyset_{i-}) - 3v_- I_+ \sin(2wt + \emptyset_{v-} - \emptyset_{i+})$$

(+) and (-) sign indicate positive and negative sequence respectively .

The zero sequence power can be express as

$$p_0 = \bar{p_o} - \tilde{p}_o$$

$$= 3V_o I_o \cos(\emptyset_{vo} - \emptyset_{io}) - 3V_o I_o \cos(2wt + \emptyset_{vo} + \emptyset_{io})$$

zero sequence power exist only if there are zero sequence voltage and current exist in the zero sequence power there is no way to eliminate the oscillation component because the average zero sequence part is always associated with the oscillating power

From figure1 it is clear that the instantaneous total power flow per unit time is $p + p_0$. Total power exchanged between the phases without transferring power is reactive or imaginary power q. The real and imaginary power does not affected by zero sequence components. In the fundamental voltage and current total power flow in a unit time is equal to the total real and zero sequence power including both average and oscillating part.

Imaginary power q is not affected by the harmonics and unbalances. It only indicates the power exchange between phases. It is not contribute to the flow of power between the source and load at any time.

HISTORI OF p-q THEORY

In 1982 p-q theory firstly publish in the Japanese language in local conference at japan, then it is published in IEEE transaction on industry application 1984, At the end of 1960 to the beginning of 1970 some paper are publish about the basic idea of compensation of reactive power. In 1976 gyugyi and pelly put the theory about compensation of reactive power without energy storage elements using naturally commuted cycloconverter. At the same year gyugyi firstly use the word active AC power filters. In 1980 and 1981 takahashi A.NABAE and k. fujiwara gives basic hint to emergence of the p-q theory.

THE p-q THEORY

The PQ theory uses Clarke transformation i.e. α-β-0 transformation. Clarke transformation convert three phase voltage and circuit into stationary reference frame by using real matrix are as follows

$$\begin{bmatrix} V_o \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_{c\beta} \end{bmatrix}$$

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

The above transformation matrix is also applicable for current transformation

The three phase four wire system is define as follows

$$\begin{bmatrix} p \\ q \\ p_0 \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta & 0 \\ -v_\beta & v_\alpha & 0 \\ 0 & 0 & v_o \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta & 0 \\ -v_\beta & v_\alpha & 0 \\ 0 & 0 & v_o \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \\ p_0 \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \frac{1}{v_0({v_\alpha}^2+{v_\beta}^2)}\begin{bmatrix} v_\alpha v_o & v_\beta v_o & 0 \\ -v_\beta v_o & v_\alpha v_o & 0 \\ 0 & 0 & ({v_\alpha}^2+{v_\beta}^2) \end{bmatrix}\begin{bmatrix} p \\ q \\ p_0 \end{bmatrix}\begin{bmatrix} i_{\alpha p} \\ i_{\beta p} \\ i_{0p} \end{bmatrix} + \begin{bmatrix} i_{\alpha q} \\ i_{\beta q} \\ i_{0q} \end{bmatrix} + \begin{bmatrix} i_{\alpha p_0} \\ i_{\beta p_0} \\ i_{0 p_0} \end{bmatrix}$$

$$= \frac{\begin{bmatrix} v_\alpha & v_\beta & 0 \\ -v_\beta & v_\alpha & 0 \\ 0 & 0 & \frac{({v_\alpha}^2+{v_\beta}^2)}{v_0} \end{bmatrix}}{({v_\alpha}^2+{v_\beta}^2)}\begin{bmatrix} p \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ q \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ p_0 \end{bmatrix}$$

$$i_{\alpha p} = \alpha - axis\ instantaneous\ active\ current = \frac{v_{\alpha p}}{{v_\alpha}^2 + {v_\beta}^2} p$$

$$i_{\alpha q} = \alpha - axis\ instantaneous\ reactive\ current = \frac{v_{\alpha q} q}{{v_\alpha}^2 + {v_\beta}^2} i_{\alpha 0} =$$

$\propto$ −axis instantaneous zero sequnce current $= 0$

$$i_{\beta p} = \beta - axis\ instantaneous\ active\ current = \frac{-v_{\beta p}}{{v_\alpha}^2 + {v_\beta}^2} p$$

$$i_{\beta q} = \beta - axis\ instantaneous\ reactive\ current = \frac{v_{\beta q} q}{{v_\alpha}^2 + {v_\beta}^2}$$

$i_{\beta q}$ − β – axis instantaneous zero sequnce current $= 0$

$$i_{0p} = 0 - axis\ instantaneus\ active\ current = 0$$

$$i_{0q} = 0 - axis\ instantaneus\ reactive\ current = 0$$

$$i_{0p_0} = 0 - axis\ zero\ sequnce\ current = \frac{p_0}{v_0}$$

by using the equation of above instantaneous reactive current instantaneous power are express follows

$$p_{\alpha p} = \alpha - axis\ instantaneous\ active\ power = v_\alpha i_{\alpha p} = \frac{{v_\alpha}^2}{{v_\alpha}^2 + {v_\beta}^2} p$$

$$p_{\alpha q} = \alpha - axis\ instantaneous\ reactive\ power = v_\alpha i_{\alpha q} = \frac{v_\alpha v_\beta}{{v_\alpha}^2 + {v_\beta}^2} q$$

$$p_{\alpha 0} = \alpha - axis\ instantaneus\ zerosequnce\ power = 0$$

$$p_{\beta p} = \beta - axis\ instantaneous\ active\ power = v_\beta i_{\beta p} = \frac{{v_\beta}^2}{{v_\alpha}^2 + {v_\beta}^2} p$$

$$p_{\beta q} = \beta - axis\ instantaneous\ reactive\ power = v_\beta i_{\beta q} = \frac{v_\alpha v_\beta}{{v_\alpha}^2 + {v_\beta}^2} q$$

$p_{\beta 0}$ − β − axis instantaneous zero sea power $= 0$

$$p_{0p} - 0 - axis\ instantaneus\ active\ power = 0$$

$$p_{0q} - 0 - axis\ instantaneus\ reactive\ power = 0$$

$$p_{0p_0} - 0 - axisin\ stantaneus\ reactive\ power = v_0 i_{0p_0}$$

APPLICATION OF pq THEORY

In the shunt current compensation Basic concept is compensation of unwanted current that is compensator inject the current such that it cancel the unwanted current in system

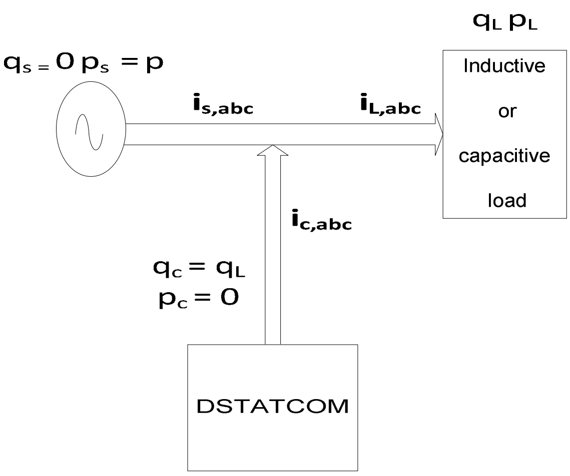


Figure2. Simplest form of shunt compensator

Figure2 show the simplest form of shunt compensator $I_{s,abc}$,show the source current . $I_{l,qbc,}$ Show the load current and $I_{c,abc}$ show the compensator current. Shunt compensator behaves as three-phase controller current source. It generates compensator current as per requirement of system.

Figure 3 Show the basic control scheme used in controller of shunt compensator. In this firstly calculate the real and reactive power then both divided into overage (φ) and oscillating part from these powers calculate the reference current.

There is no any exchange of real power in compensator there for compensator does not required any power source or energy storage system.

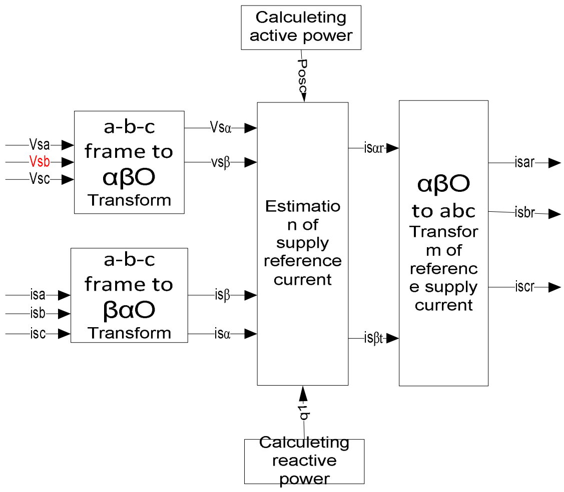
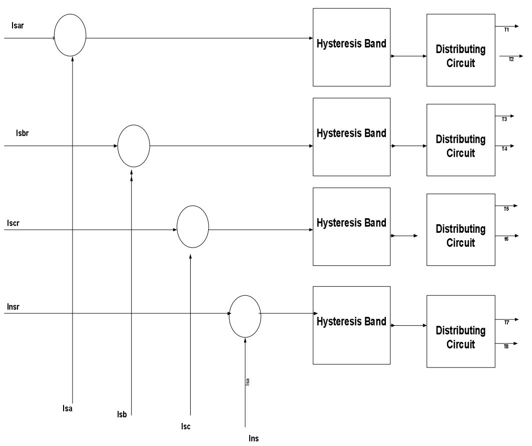


Figure3. The basic scheme of reference current generation in shunt compensator

CURRENT CONTROL

The hysteresis band current control technique has proven to be most suitable for all the applications of current controlled voltage source inverters in active power filters. The hysteresis band current control is characterized by unconditioned stability, very fast response, and good accuracy. In hysteresis control, rapid switching of each switch according to the continuous measurement of the difference between the actual supply current and reference sinusoidal current. The basic principle of current hysteresis control technique is that the switching signals are derived from the comparison of the current error signal with a fixed width hysteresis band .

For hysteresis control the phase output current is fed back to compared with the reference current. An upper tolerance band and a lower tolerance band, taken as of, are also assigned in order to define an acceptable current ripple level. Whenever the phase current exceeds the upper band, the upper switch of that leg will be turned ON while the lower switch will be turned OFF. If phase current falls below the lower band, the upper switch will be turned OFF whereas the lower switch will be turned ON.



CONCLUSION

In this paper a basic p-q theory using Clarke transformation has been presented. In this theory reference currents and voltages in shunt and series compensation respectively are generated on the basis of average and oscillating component of power.

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