Analysis and Control of Shunt Active Power Filter by Use of P-Q and D-Q Theories

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Abstract- **In general, large usage of power electronic based equipment introduces the harmonics in the distribution system. Hence, the nonlinear loads of industrial and domestic introduce the nonlinearity in the distribution system. Because of these nonlinear loads, the system voltage and current waveforms getting distort since the nonlinear loads introduces the harmonic content in the source consequently the power factor of the source reduces. These harmonics along with the less power factor causes various problems such as increases the losses in the transmission, distribution systems, overheating of transformers and motors, flickering effect in florescent tubes and operational failure of protective relaying etc. To reduce the harmonic currents in the power system and maintain the power quality, a Shunt active power filter (SAPF) based on pq and d-q theories is used. Here, p-q theory has Clarke transformation for extracting the reference currents whereas the d-q theory consists of Park transformation along with the phase locked loop (PLL). The DC link voltage is regulated by using the PI and fuzzy logic controllers. Moreover, hysteresis current control technique is used to drive the voltage source inverter(VSI) and the shunt active power filter based on p-q and d-q theories for different DC link control strategies such as PI and Fuzzy under steady state and load variation is simulated in MATLAB.**

Index terms- Cold formed Channel Section, Compression, Load carrying capacity of Section, UTM, Folded Flange, etc

I. INTRODUCTION

Nonlinear loads [1] such as power electronic based equipment's introduce the harmonics in the power system. High power diode/Thyristor rectifiers, Cyclo converters and arc furnaces characterized as identified nonlinear loads because utilities identify the individual nonlinear loads installed by high power consumers. Low power diode rectifier used for electric interface typically considered as unidentified nonlinear load. Due to harmonics overheating of electrical transformers and motors increases since the core loss in these equipment's depends on the frequency, in some cases harmonic spectra contains the frequency components below the line frequency causing voltage flickering effect in incandescent lamps, interference with the communication lines, causes the voltage waveform distortion particularly in the rectifier devises. Passive filters are also uses for the harmonic mitigation but these are having certain demerits. The demerits of passive filters are filtering out the harmonics, which are pre-defined, occurrence of resonance when they use in the circuit and operation is limited to certain type of loads. Therefore, to overcome these demerits active filters came into field.

1.1 Effect of harmonics

- The Harmonics are the integral multiple of the fundamental frequency. In the electric motors and transformers, the losses are proportional to the frequency. Therefore, it leads to the increment in the losses ultimately overheating in the transformers and motors.
- Generally, capacitors are used for the power factor correction. Due to the harmonics, overcurrent may flow through the these capacitors results in overheating and damage of the capacitors
- Harmonics currents sometimes distort the voltage waveform, which affects the other loads which are connected to the system.
- In some cases, harmonics occurs below the line frequency. Harmonics below the line frequency are called sub harmonics. The sub harmonics are in the range of 8Hz to 28Hz. Sub harmonics

causes the flickering effect in the florescent tubes and also affects the human eye.

II. SHUNT ACTIVE POWER FILTER

Non-linear loads introduce the harmonics in the supply system such that the other consumers, which are connected to the supply system, are affected due to these harmonics. Non-linear loads draw the fundamental component of the active current and may draw the reactive currents. Due to these non-linear loads, source current gets distorted which will affect the other consumers connected to the distribution system. Shunt active power filter functions such that it compensates the harmonic currents and reactive currents drawn by the load.

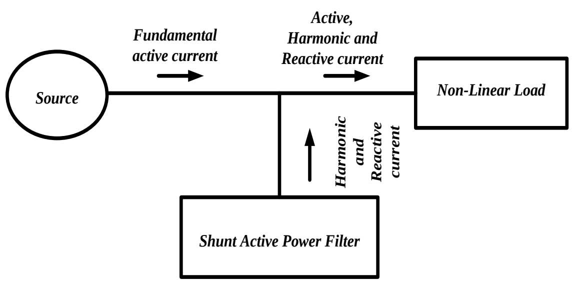


Fig.2.1 shunt active motor

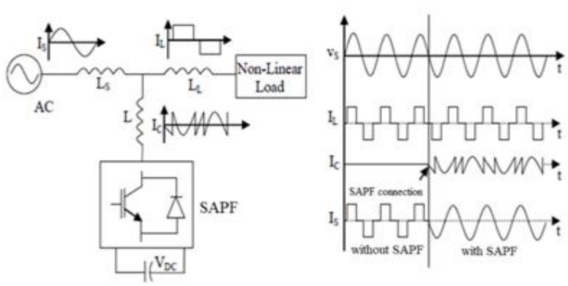


Fig.2.2.shunt active filter

III.COMPENSATION CURRENT EXTRACTION

In this thesis, p-q theory and d-q theory are proposed for the reference compensation current extraction. Both the theories proposed in this thesis are based on the indirect current control. Indirect current control provides better performance and requires less hardware circuitry than direct current control. These reference compensation currents are compared for actual compensation currents injected by the shunt active power filter for generating the gating pulses for voltage source inverter. The proposed theories for extracting the reference compensation currents are

1. p-q theory
2. d-q theory

3.1 p-q THEORY:

p-q Theory developed by using the instantaneous powers, which are defined in the time domain. p-q Theory doesn’t have any restrictions on the current and voltage waveforms. This theory can be applied to any three phase-three wire systems consisting with (or) without neutral. This theory is not only valid for steady state but also valid for transient state. So many traditional methods are there, which are implemented by considering the three phase system as three single-phase systems. But this theory is very flexible and efficient for designing the active power filters, which are based on the power electronic converters. The first step in the p-q Theory is that transforming the all voltages and currents from a-b-c co-ordinates to the αβco-ordinates, which is called as the Clarke transformation. Clarke transformation consists of a real matrix that transforms all three-phase voltages and currents from a-b-c axes to αβ stationary frame. p-q Theory starts with the Clarke transformation.

$$\begin{bmatrix} p_\alpha \\ p_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha i_\alpha \\ v_\beta i_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha i_{\alpha p} \\ v_\beta i_{\beta p} \end{bmatrix} + \begin{bmatrix} v_\alpha i_{\alpha q} \\ v_\beta i_{\beta q} \end{bmatrix}$$

3.2 d-q THEORY:

Three phase load currents are converted from a-b-c axes to d-q using park transformation. It involves two steps. Firstly, transforming stationary a-b-c reference frame into stationary α-β reference frame and then stationary α-β reference into synchronously rotating reference frame.

IV. CONTROLLER LOGICS

4.1 PI controller

The actual capacitor voltage is compared with the reference set voltage and the error voltage is processed through the PI controller to reduce the error. Here PI controller minimizes the error between the actual capacitor voltage and the set reference voltage such that actual capacitor tracks the reference voltage. PI controller is a linear combination of proportional and integral gains. The transfer function of PI controller is given in equation.

$$G(s) = K_p + \frac{K_i}{s} \qquad (5.4)$$

Here Kp is the proportional gain, which determines the dynamic response of the DC link voltage and Ki is the integral gain, which reduces the steady state error thereby determines the settling time. Here the values of proportional and integral gains are determined in such a way that the error voltage being minimized.

Fig. 5.6.Shows the block diagram of PI controller. Here PI controller requires the precise mathematical model. It is difficult during the dynamic conditions.

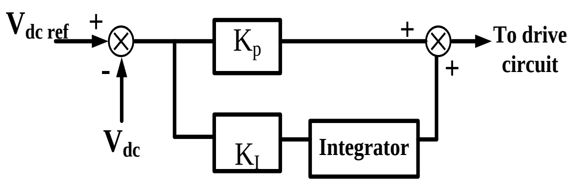


Fig.4.1 Block diagram of PI controller

4.2 Fuzzy Logic Controller

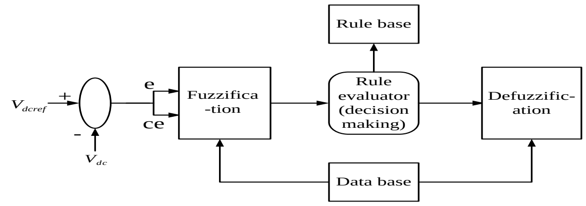
Fuzzy logic control is derived from set theory. Fuzzy logic is first introduced in 1965 by Zadeh. Fuzzy logic control deals with the linguistic variables, therefore it gives very accurate results in control applications. In SAPF fuzzy logic controller is used to minimize the error between the actual capacitor voltage and the reference capacitor voltage. Fuzzy logic controller does not require any mathematical model. It depends only on the linguistic variables, therefore fuzzy logic controller gives precise results. Here the fuzzi logic implication is by using the Mamdani minimum operator. Fuzzy logic controller consisting of the following blocks, which are given below.

1. Fuzzification
2. Data base
3. Rule base
4. Deduzzification

Rule base: Rule base defines the set of control rules for decision-making. The rule base for the given implemented fuzzy logic controller is shown in the Table. 5.1.

e(n) *ce(n)*	*NH*	*NM*	*NL*	*Z*	*PL*	*PM*	*PH*
NH	NH	NH	NH	NH	NH	NL	Z
NM	NH	NH	NH	NM	NL	Z	PL
NL	NH	NH	NM	NL	Z	PH	PM
Z	NH	NM	NL	Z	PL	PM	PH
PL	NM	NL	Z	PL	PM	PH	PH
PM	NL	Z	PS	PM	PH	PH	PH
PH	Z	PL	PM	PH	PH	PH	PH

Table. 4.1. Rule base



Here nonlinear load comprising diode rectifier with RL load.

Parameter	Value
Source Voltage	100V (line-line RMS)
Source Resistance	10mΩ
Source inductance	10mH
Load resistance	R1=50 Ω, R2=30 Ω
Load inductance	L1=100mH, L2=100mH
Dc link Capacitance	2000e-6
Dc link Voltage	300V
Filter inductance	4mH

Table4.2.System parameters for simulation study

V. SIMULATION RESULTS

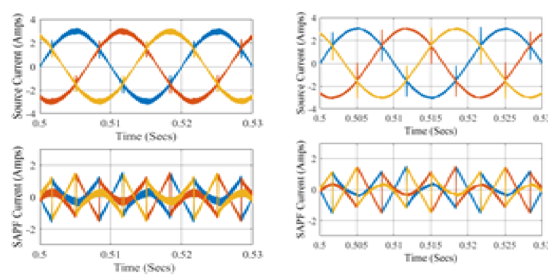


Fig. 5.1 i_S and i_F with PI, Fuzzy controller

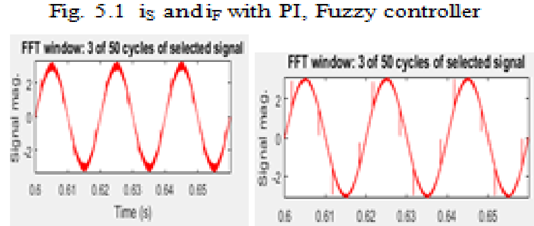


Fig. 5.2 FFT cycle of iS with PI, Fuzzy controller

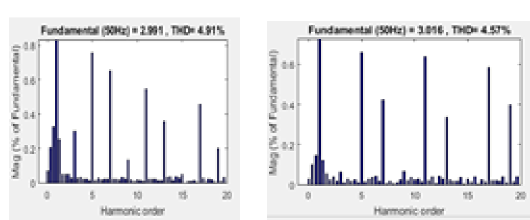


Fig 5.3 performance analysis of pq sapf under steady state condition

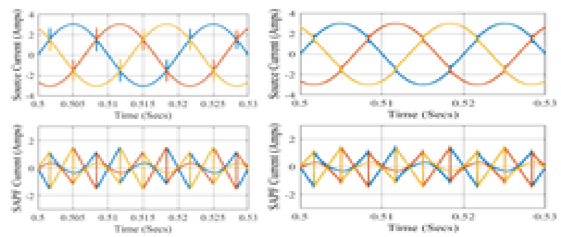


Fig. 5.4 i_S and i_F with PI, FUZZY controller

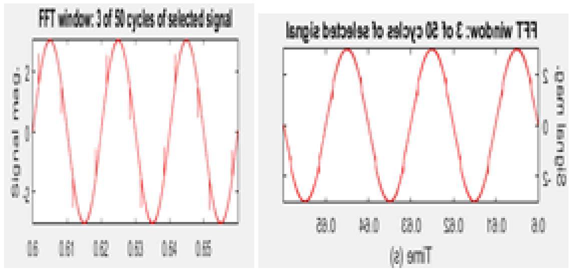


Fig 5.5. FFT cycle of i_S with PI, FUZZY controller

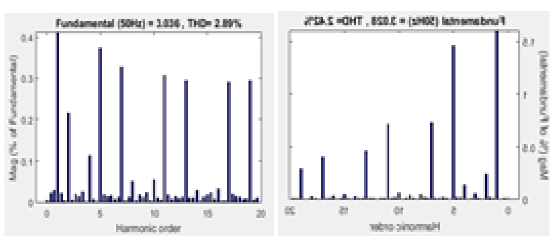


Fig. 5.6 THD of iS with PI, FUZZY controller

TABLE 5.1 RESULTS OF SHUNT ACTIVE POWER FILTER BY USE OF P-Q AND D-Q

	Without SAPF	PI (pq)	FUZZY (pq)	PI (dq)	FUZZY (dq)
1	30.64%	4.91%	4.57%	2.89%	2.42%
2	29.92%	8.65%	5.29%	3.78%	3.54%

The total harmonic distortion (THD) analysis of pq SAPF and dq SAPF under state state and node variation.

VI.CONCLUSION

SAPF based on p-q and d-q theories with PI and fuzzy logic DC voltage controllers under steady state and load variation are simulated in the MATLAB environment. Under steady state, THD in the source current before connecting the SAPF is 30.64%. The THD obtained in source current after connecting the pq-SAPF with PI and Fuzzy controller is reduced to 4.91% and 4.57%, respectively. Now, THD in the source current after connecting the dq-SAPF with PI controller is 2.89%, whereas THD in the source current is further reduced significantly to 2.42% with fuzzy logic controller as compared to above control schemes. The source current THDs performance after increment of the load before and after connecting SAPF with PI and fuzzy logic controllers are 29.92%, 8.65% and 5.29% respectively. Moreover, the THDs behavior of dq-SAPF with PI and fuzzy are also checked under above mentioned loads and are obtained 3.74% and 3.54%, respectively. Moreover, the source current THD of dq-SAPF with fuzzy is improved before and after increment of the load by 50.7% and 59.07% respectively as compared to conventional pq-SAPF with PI.

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