Modelling and Analysis of D-Q Based Controller for Shunt Active Power Filter to Improve Power Quality

[1]Ramireddy Vinod, [2]T. Rama Subba Reddy

[1]M.Tech student (PEED),[2]Prof & Head of the Department, Vignan Institute of Technology & Science,

Abstract: With the development in technology there has been drastic increase in the use of power electronic equipment's resulting in the increase of harmonics in source current or ac mains current. Now a day's, Nonlinear loads are widely used in industries. The Nonlinear loads like Arc furnaces, locomotives, welding equipment's, fluorescent lamps etc..; generate harmonics into the power system. Due to these nonlinear loads, draws non-sinusoidal current and create voltage drops in the power system and also overheating of equipment's, communication interference, capacitor failure etc... Therefore, it is considerable to reduce or eliminate the harmonics in the system. Conventionally, L-C passive filters were used to solve the problem of harmonics to filter out current harmonics to get sinusoidal supply current.

Modern Active power filter's (APF) are superior in harmonic's filtering performance compared to traditional passive filters. Among the SSAF and SAPF, Shunt Active Power Filter (SAPF) is most preferred because this filter provides higher efficiency and more flexible compared with a passive power filter. Shunt active power filter (SAPF) with power circuit either a voltage -sourced PWM converter equipped with a DC capacitor or a current-sourced PWM converter equipped with a DC inductor. This filter have the multiple functions like harmonic filtering, damping, isolation and termination, reactive power control for power factor correction and voltage regulation, voltage-flicker mitigation.

In this paper, it is planned to design a d-q based controller for VSC based active power filter for harmonic compensation. The simulation results have been done by using MATLAB/SIMULINK.

Key words: active filter, harmonics, STATCOM, THD.

I. INTRODUCTION

The growing use of non-linear and time-varying loads has led to distortion of voltage and current waveforms and increased reactive power demand in ac mains. Harmonic distortion is known to be source of several problems, such as increased power losses, excessive heating in rotating machinery, significant interference with communication circuits and audible noise, incorrect operation of sensitive loads .Passive filters are traditional method to eliminate harmonics, but with recent developments in power semiconductor switches and converters, coupled with developments in control techniques and analog and digital implementations, active filters are becoming an effective and commercially viable alternative to passive filters. The SAPF based on voltage source inverter (VSI) is the most common one because of its efficiency. The performance of Active power filters depends on the adoptive control approaches.

There are so many mitigation techniques for harmonics elimination. Traditionally, the simplest method to eliminate current harmonics is the usage of passive LC filters, but they have many drawbacks such as large size, tuning problems, resonance and fixed compensation characteristics, the solution over passive filters for compensating the harmonic distortion and unbalance is the SAPF. In order to compensate the distorted currents.[1]

a) Three Phase voltage source inverter:

Single-phase VSIs cover low-range power applications and three-phase VSIs cover the medium- to high-power applications. The main purpose of these topologies is to provide a three-phase voltage source, where the amplitude, phase, and frequency of the voltages should always be controllable. The gating has been done by sinusoidal PWM method or Space Vector PWM method.[2],[3]

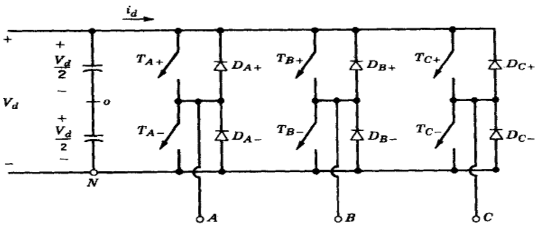


Figure 1: Three phase VSI

II. APF CONTROL METHODS

This section briefly reviews three techniques for the estimation of the reference compensation current of the APF. A description of the well-known (conventional) p-q and d-q methods is presented, which is followed by a description of the d-q theory method.

a) Instantaneous Active Power Theory (p-q Theory)

The instantaneous and reactive power method, proposed by Akagi[4], remains one of the most popular APF control schemes.

$$\begin{bmatrix} V\alpha \\ V\beta \\ V0 \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

$$\begin{bmatrix} i\alpha \\ i\beta \\ i0 \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix}$$

$$P\alpha\beta = V\alpha i\alpha + V\beta i\beta$$

$$Q\alpha\beta = V\alpha i\beta - V\beta i\alpha$$

$$\overline{\overline{P}} = \tilde{P} + \vec{P}, \overline{\overline{Q}} = \tilde{Q} + \vec{Q}$$

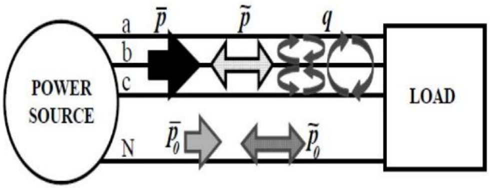


Figure 2: Power Components in P-Q theory

b) Synchronous Reference Frame Method (d-q Method)

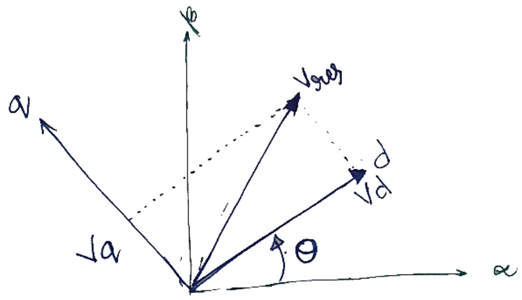


Figure 3: d-q theory

The d-q method is the most studied and the load currents are transformed into the d-q components in order to separate the fundamental and harmonics components of instantaneous currents (id, iq).

$$\begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} Ila \\ Ilb \\ Ilc \end{bmatrix}$$

$$\begin{bmatrix} Ild \\ Ilq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} Il\alpha \\ Il\beta \end{bmatrix}$$

Where $\theta = \tan^{-1}\left(\frac{V\beta}{V\alpha}\right)$

$$\overline{\overline{Ild}} = \widetilde{Ild} + \overrightarrow{Ild}, \overline{\overline{Ilq}} = \widetilde{Ilq} + \overrightarrow{Ilq}$$

One of the main differences of this method from p-q theory is that the d-q method requires the determination of the angular position of the synchronous reference of the source voltages; for this a PLL algorithm is used. After the transformation of load currents into the synchronous reference, a low-pass or high-pass filter is using to separate the fundamental and harmonic components. Finally, the reference currents are transformed to the three phase reference using the inverse synchronous transform.[5]

III. ACTIVE POWER FILTER (APF)

Unlike the traditional passive filters, modern active filters have the multiple functions like harmonic filtering, damping, isolation and termination, reactive power control for power factor correction and voltage regulation, voltage flicker mitigation and load balancing. Significant cost reductions in both power semiconductor devices and signal processing devices have inspired manufactures to put active filters on the market. It can also use commercially. The operation of APF depends on algorithm to controller.

Shunt Active Power Filters (SAPF)

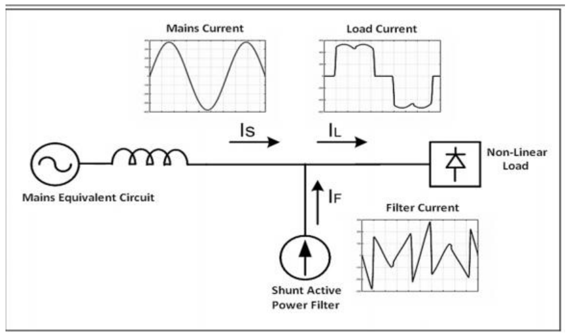


Figure 1 : SAPF Basic compensation principle

Shunt active filters mainly consist of two main blocks, The PWM converter (power processing) and the active filter controller (signal processing)

Principle of operation:

The shunt-connected active power filter, with a self-controlled dc bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase-shifted by 180. So, SAPF operates mainly in two modes

a) STATCOM mode,

b) Harmonic Compensation.

3.1 STATCOM mode of operation:

Static Synchronous Compensator (STATCOM) is a part of the Flexible Alternating Current Transmission systems (FACTS) device family.

STATCOMs can be used for Voltage regulation at the receiver end of ac transmission lines, thus replacing banks of shunt capacitors. STATCOMs are commonly used for dynamic power factor correction (i.e., dynamic reactive power compensation) in industrial plants operating with large random peaks of reactive power demand.

a) VAR compensation:

The STATCOM has to compensate the reactive power demand by generating leading or lagging VAR at PCC.

The output voltage of Inverter can be controlled both in magnitude and phase, which is coupled to system voltage through a relatively small (0.15 -0.2 p.u) tie reactance (which in practice may be provided by per phase leakage inductance of coupling transformer). The source, load, converter measure instantaneous active (P) and reactive (Q) power components.

For full compensation of load, converter has to supply reactive power (Q) of same magnitude, but of opposite sign. So, reactive power drawn from source is zero, thus unity power factor can be achieved.

$$\mathrm{Qsource} = \mathrm{Qload} + \mathrm{Q\ inverter}$$

Under complete compensation

$$\mathrm{Qsource} = \mathrm{Qload} + \mathrm{Q\ inverter} = 0$$

STATCOM has to draw active power from grid to maintain DC link voltage at desired level.

$$\mathrm{Psource} = \mathrm{Pload} + \mathrm{Pstatcom}$$

The Iq loop in the controller alone controls the reactive power flow in the system. [6]

The direction of flow of reactive power whether it is from coupling transformer to the system or from system to the coupling transformer depends upon the difference between the converter output voltage and the ac system bus voltage.

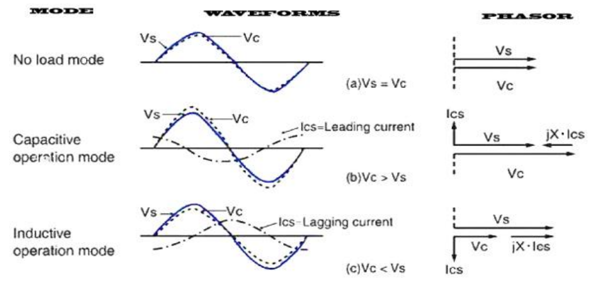


Figure 2 : STATCOM modes of operation

3.2 Harmonic Compensation:

Synchronous frame theory (d-q theory) based controller is chosen because it has greater and better performance when the supply voltage distorted. The advantage with SRF method is any Non dc component presented can be filtered easily because the fundamental components turned as dc components.

3.3 Active and Reactive Power in d-q frame:

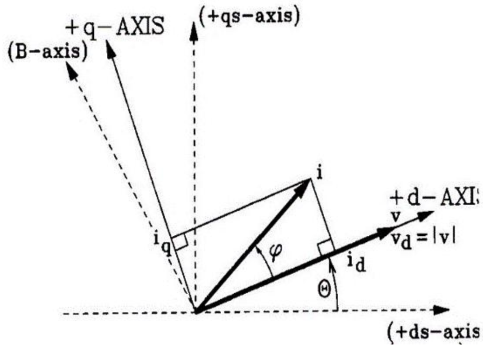


Figure 3 : illustration of rotating reference frameconcept

- The voltages Vabc are transformed to d-q components such that with an added advantage of d-q theory the voltage axis is aligned in with the d-axis such that the component along the q or quadrature axis will be zero. So $\mathrm{Vd} = |\mathrm{V}|\&\mathrm{Vq} = 0$
- The same transformation applied for currents Iabc such that the vector "I" makes an angle "Ψ" where Ψ refers to phase angle. Such that from figure $\mathrm{Id} = \mathrm{Icos}\Psi$ and $\mathrm{Iq} = \mathrm{Isin}\Psi$.
- From basic definitions of Active power and Reactive power

$$\mathrm{P} = \mathrm{VICOS}\Psi$$

$$\mathrm{Q} = \mathrm{VISIN}\Psi$$

So for a given system voltage will be constant so, $\mathrm{P}\ \alpha\ \mathrm{Id}$and $\mathrm{Q}\ \alpha\ \mathrm{Iq}$.

"So, active power control indirectly means controlling of **Id** component and reactive power control indirectly means controlling of **Iq** component."

IV. MATHEMATICAL MODELLING OF THE COMPENSATOR

In order to obtain the controller for the compensator, first a mathematical model is derived. The below figure shows the compensator where VSI is connected to grid through a coupling reactor of inductance L and resistance R.

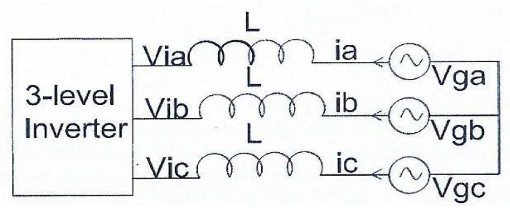


Figure 4 : Schematic of SAPF Model

Where $\mathrm{Via}, \mathrm{Vib}, \mathrm{Vic}$ are generated inverter voltages, $\mathrm{ia}, \mathrm{ib}, \mathrm{ic}$ are inverter currents and $\mathrm{Vga}, \mathrm{Vgb}, \mathrm{Vgc}$ are grid/source voltages.

From the fig 7, Voltage equation in stationary a-b-c frame is

$$\begin{bmatrix} Vga \\ Vgb \\ Vgc \end{bmatrix} = \begin{bmatrix} Ldia/dt \\ Ldib/dt \\ Ldic/dt \end{bmatrix} + \begin{bmatrix} Via \\ Vib \\ Vic \end{bmatrix} \ldots (1)$$

The above equation is assumed under the power system is balanced, harmonics are absent and R is small. The a-b-c frame equations can be transformed according to α-β theory.

$$\begin{bmatrix} Vs\alpha \\ Vs\beta \end{bmatrix} = \begin{bmatrix} L\, di\alpha/dt \\ L\, di\beta/dt \end{bmatrix} + \begin{bmatrix} Vi\alpha \\ Vi\beta \end{bmatrix} \ldots (2)$$

The α-β components transformed to d-q components

$$\mathbf{Vid} = \mathbf{Vsd} - \mathbf{Ldid/dt} + \boldsymbol{\omega}\mathbf{Liq} \ldots. (3)$$

$$\mathbf{Viq} = \mathbf{Vsq} - \mathbf{Ldiq/dt} - \boldsymbol{\omega}\mathbf{Lid} \ldots.. (4)$$

The equations (3), (4) are model of physical system which consists of converter connected to AC system. In the above equation $Ldid/dt$, $Ldiq/dt$ are PI controller outputs of respective current control loops.

4.1 Control strategy of SAPF:

The controller main function is to supress the harmonics present in the source due to load. From the d-q theory the active and reactive current drawn by the load could be expressed by several components.

$$Id = Idfund + Idharmonic$$

$$Iq = Iqfund + Iqharmonic$$

Controller:

From the above equations (3) & (4), current components such as Id, Iq are coupled through term "ω" and it is known that reference current tracking capability of controllers is not good and rapid enough for coupled systems.

To achieve the objective of a controller and also to improve the performance and reduce the interaction between Id, Iq controls, a decoupled controller is necessary.[7][8]

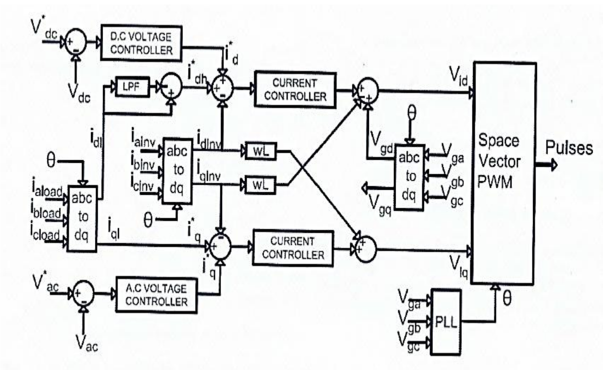


Figure 5 : Control block diagram for SAPF

V. SIMULATION & RESULTS

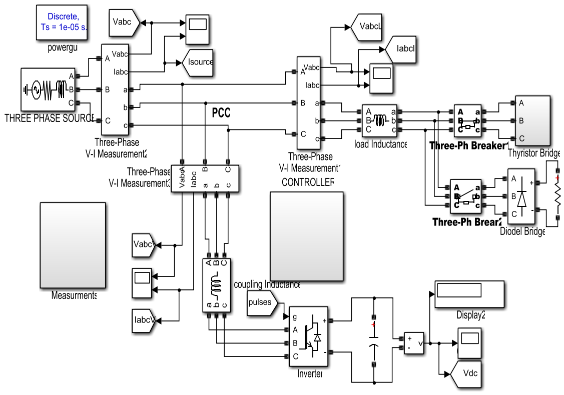


Figure 6 : Power system Simulink model with SAPF

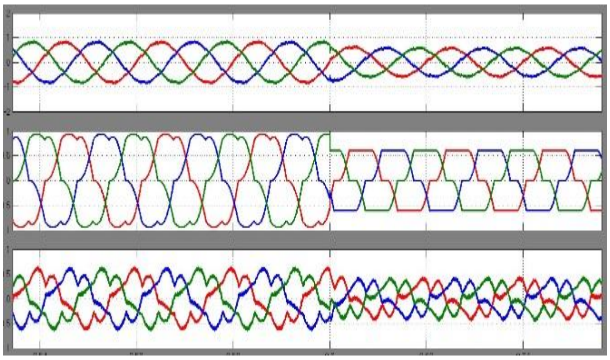


Figure 7 : source, load & Inverter currents of DBR & TBR with SAPF

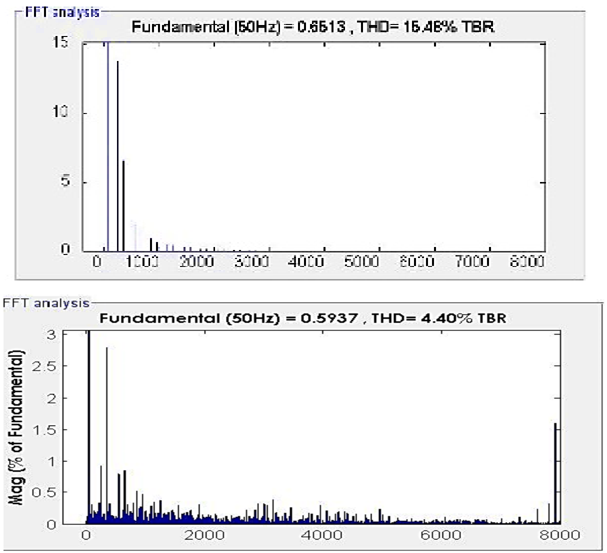
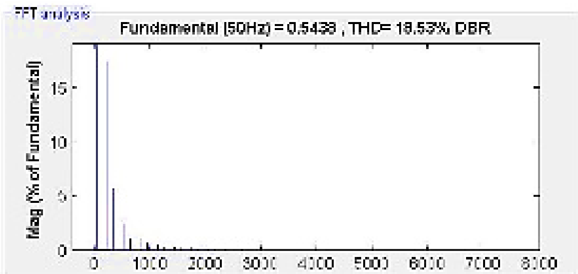


Figure 8 : Harmonic spectrum of TBR without & with SAPF



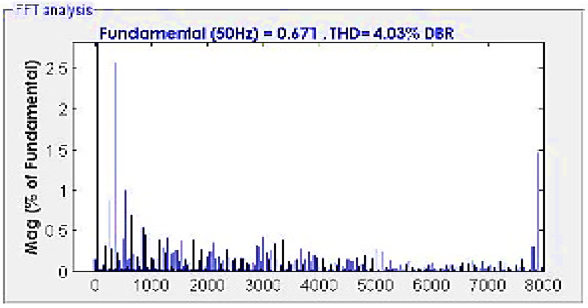


Figure 9 : Harmonic spectrum of DBR without & with SAPF

VI. CONCLUSION

In this paper, the d-q based controller for SAPF is modelled. In this 500KVA, 0.8pf, 415V, 50Hz power system is considered for modelling of SAPF and it is able to compensate reactive power and mitigate harmonics such that it improves power quality.

It is readily available for real time operation using DSP.The paper presents the design of controller for SAPF, based on state-of-the-art powerelectronics technology and also their future prospects and directions.

Future Scope

The better harmonic reduction can also obtained by using Multi Level Inverters [MLI] mainly Neutral Point Clamped converter. The DC bus utilization for this MLI is also less compared to conventional two level VSI.

REFERENCES

[1] L.R.Limongi, M.CCCavalcanti, F.A.S.Neves, G.M.S.Azevedo “Implementation of aDigital Signal Processor-controlled Shunt Active Filter.” UFPE.Recife-PE-Brasile.

[2] P.Tripura, Y.S.KishoreBabu, Y.R.Tagore “Space Vector Pulse Width Modulation Schemes for Two-Level Voltage Source Inverter” ACEEE Int. J. on Control System and Instrumentation, Vol. 02, No. 03, October 2011.

[3] “High power converters and AC drives” by binwu, IEEE press A John Wiley & Sons, Inc., Publication.

[4] H.Akagi “Modern active filters and traditional passive filters” bulletin of the polish academy of sciences technical sciences vol 54, No. 3, 2006.

[5] “Generalised Machine theory” by Dr. P. S. Bimhra, Khanna Publications.

[6] S.Eswara Rao, Dr. B. P. Muni, JVR Vithal, SN saxena “Development of ± 500 kVAR DSTATCOM for distribution utility and industrial applications”,IEEE,TENCON 2003. Conference on Convergent Technologies for the Asia-Pacific Region , 278 - 282 Vol.1.

[7] S.Eswara Rao, Dr. B. P. Muni, Prashanth Jain and CPV Reddy,”Development of 2.5MVAR STATCOM for arc furnace applications”,Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference, pg 1-6

[8] AlperAkdag, susumuTadakuma, Hideaki Minakata, “Load balancing control by symmetrical coordinates frame for PWM inverter based Reactive Power Compensators”, T.IEE Japan, Vol.131-D, no1, 2001.