Performance of Active Power Filters and their Applications for Power Generation Systems

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Abstract— Active filters have become a viable alternative for controlling harmonic levels in industrial and commercial facilities. However, there are many different filter configurations that can be employed and there is no standard method for rating the active filters. The compensation for harmonic and reactive currents becomes increasingly important owing to the wide use of power electronic equipment. Traditionally, passive LC filters have been used to eliminate line current harmonics and to increase the power factor. However, in practical applications these passive filters present many disadvantages, such as aging and tuning problems, series and parallel resonances and others. In order to overcome these problems, many compensated methods based on the technique of power electronics have been researched and developed recently, one of them is active power filters, which have gradually been recognized as a feasible solution to the problems created by nonlinear loads. They are used to eliminate the unwanted harmonics and compensate power factor by injecting equal but opposite compensation currents. An active power filter, a current source, connected in parallel with the nonlinear load, is controlled to generate the required compensation currents, so the main only needs to supply the fundamental current. Besides eliminate harmonic currents and compensate power factor, this kind of active power filter can keep the power system balanced under the condition of unbalanced and nonlinear loads simultaneously, if the compensation currents include harmonic, reactive, fundamental negative sequence and zero sequence currents. A detailed yet simple mathematical model of the active power filter, including the effect of the equivalent power system impedance, is derived and used to design the predictive control algorithm. The compensation performance of the proposed active power filter and the associated control scheme under steady state and transient operating conditions is demonstrated through simulations and experimental results.

Key words: Active Power Filter (APF) , FBD Algorithm, Total Harmonic Distortion (THD), Electromagnetic Interference (EMI), Shunt Active Power Filter (SAPF), Point Of Common Coupling (PCC), Metropolitan Electricity Authority (MEA), Power Theory (PQ), Synchronous Reference Frame (SRF), D-Q Axis With Fourier (DQF), And The Synchronous Detection (SD), Pulse Width Modulation (PWM), And Space Vector Modulation (SVM), Proportional Integral (PI), VSI (Voltage Source Inverter), CSI (Current Source Inverter), Insulated Gate Bipolar Transistor (IGBT), Insulated Gate Commutated Thyristors (IGCTS) And Injection Enhanced Gate Transistors (IEGTS), Neutral Point Clamped (NPC), Silicon-Controlled Rectifiers (SCRS), Gate Commutated Thyristors (GCTS), Or Symmetrical Gate Commutated Thyristors (SGCTS), Active Front End (AFE), Gate Turn-Off Thyristor (GTO)

I. Introduction

In a modern power system, increasing of loads and nonlinear equipment's have been demanding the compensation of the disturbances caused for them. These non-linear loads may cause poor power factor and high degree of harmonics [1]. Active power filter (APF) can solve problems of harmonic and reactive power simultaneously.

APF's consisting of voltage source inverters and a dc capacitor have been researched and developed for improving the power factor and stability of transmission systems. APF have the ability to adjust the amplitude of the synthesized ac voltage of the inverters by means of pulse width modulation or by control of the dc-link voltage, thus drawing either leading or lagging reactive power from the supply. APF's are an up-to-date solution to power quality problems.

Shunt APF's allow the compensation of current harmonics and unbalance, together with power factor correction, and can be a much better solution than conventional approach (capacitors and passive filters). The simplest method of eliminating line current harmonics and improving the system power factor is to use passive LC filters.

Harmonic compensations have become increasingly important in power systems due to the widespread use Of adjustable-speed drives, arc furnace, switched-mode power Supply, uninterruptible power supply, etc. Harmonics not only Increase the losses but also produce unwanted disturbance to the communication network, more voltage and/or current Stress, etc. Different mitigation solutions [2], e.g., passive filter, Active power line conditioner, and also hybrid filter, have been Proposed and used.

Recent technological advancement of switching devices and availability of cheaper controlling devices, E.g., DSP-/field-programmable-gate-array-based system, Make active power line conditioner a natural choice to compensate for harmonics. Shunt-type active power filter (APF) is used to eliminate the current harmonics.

The dynamic performance of an APF is mainly dependent on how quickly and how accurately the harmonic components are extracted from the load current. Many harmonic extraction Techniques are available, and their responses have been explored. In this project a new concept is proposed that is FBD algorithm in three-phase four-wire shunt active power filter to compensate the harmonics.

In APF design and control, instantaneous reactive power theory was often served as the basis for the calculation of compensation current. In this theory, the mains voltage was assumed to be an ideal source in the calculation process. The *p–q* theory, since its proposal, has been applied in the control of three-phase active power filters. However, power system voltages being often non-ideal, in distorted voltage systems the control using the *p–q* theory does not provide good performance. For improving APF performance under non-ideal mains voltages, new control methods are proposed by Komatsu and Kawabata and Huang and Chen and Hsu. In this paper, the proposed control algorithm gives adequate compensating current reference even for non-ideal voltage system [9].

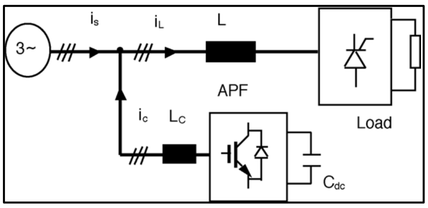

Fig. 1: Block diagram of APF

II. ACTIVE POWER FILTER

Fig. 1 shows basic APF block diagram including non-linear load on three-phase supply condition. In this study, three-phase controlled thyristor bridge rectifier with ohmic–inductive loading are considered as a non-linear load on three-phase ac mains. This load draws non-sinusoidal currents from ac mains and can be controlled by changing its firing angle.

Shunt active power filters are developed to suppress the harmonic currents and compensate reactive power simultaneously [3]. The shunt active power filters are operated as a current source parallel with the non-linear load.

In this situation, the mains current is sinusoidal and in phase with mains voltage. A voltage-source inverter having IGBT switches and an energy storage capacitor on dc bus is implemented as a shunt APF. The main aim of the APF is to compensate harmonics, reactive power and to eliminate the unwanted effects of nonideal ac mains supplies only unity power factor sinusoidal balanced three-phase currents. Shunt active filters are designed to compensate for harmonic currents, reactive power and neutral current by injecting filtering currents into the electric grid.

The simplest control technique for current controlled PWM inverters, used as an APF, is hysteresis control. However, at critical points, where changes of reference waveform slope are unpredictable, hysteresis control causes a dangerous increase in switching frequency which cannot be justified, even if it has the advantage of not exceeding the designed error band [4]. The proposed current control, on the other hand, aims to reduce tracking error, by means of a fixed frequency driving signal.

III. POWER QUALITY

The power quality of power supply of an ideal power system means to supply electric energy with perfect sinusoidal waveform at a constant frequency of a specified voltage with least amount of disturbances. Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage.

In this part we introduces the commonly accepted definitions used in the field of power quality and discusses some of the most pertinent issues affecting end-users, equipment manufacturers and electricity suppliers relating to the field [7]. This Special Feature contains a range of articles balanced to give the reader an overview of the current situation with representation from the electricity industry, monitoring equipment manufacturers, solution equipment manufacturers, specialist consultants and government research establishments. The term ‘power quality’ has come into the vocabulary of many industrial and commercial electricity end-users in recent years. Previously equipment was generally simpler and therefore more robust and insensitive to minor variations in supply voltage. Voltage fluctuations coming from the public supply network were therefore not even noticed.

A voltage dip is a reduction in the RMS voltage in the range of 0.1 to 0.9 p.u. (retained) for duration greater than half a mains cycle and less than 1 minute. Often referred to as‘sag’. Caused by faults, increased load demand and transitional events such as large motor starting. A voltage swell is an increase in the RMS voltage in the range of 1.1 to 1.8 p.u. for a duration greater than half a mains cycle and less than 1 minute. Caused by system faults, load switching and capacitor switching.

IV. HARMONICS

Harmonics are periodic sinusoidal distortions of the supply voltage or load current caused by non-linear loads. Harmonics are measured in integer multiples of the fundamental supply frequency. Using Fourier series analysis the individual frequency components of the distorted waveform can be described in terms of the harmonic order, magnitude and phase of each component [5,8]. The electricity is produced and distributed in its fundamental form as 50hz in India.

A harmonics is defined as the content of signal who’s frequency is integer multiple of the system fundamental frequency. Due to harmonic effect the sinusoidal waveform is no longer have stand and it became non-sinusoidal or complex waveform. The complex waveform consists of a fundamental wave of 50 Hz and a number of other sinusoidal waves whose frequencies are integral multiple of fundamental wave like 2f(100hz). 3f (150 Hz), 4f (200 Hz) etc. Wave having frequency of 2f, 4f, 6f etc. are called the even harmonics and those having frequency of 3f, 5f, 7f etc are called as odd harmonics.

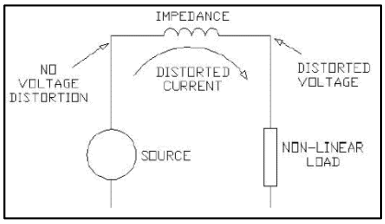

Fig. 2: Distorted-current induced voltage distortion

V. TOTAL HARMONIC DISTORTION (THD)

The THD is defined as the ratio of the rms value of the harmonic components to the rms value of the fundamental component and usually expressed in percent. This index is used to measure the deviation of a periodic wave form containing harmonics from a perfect sine wave. For a perfect sine wave at fundamental frequency, the THD is zero.

VI. CLASSIFICATION OF ACTIVE POWER FILTERS

An unfavourable but inseparable feature of APF is the necessity of fast switching of high currents in the power circuit of the APF. This results in a high frequency noise that may cause an electromagnetic interference (EMI) in the power distribution systems. APF can be connected in several power circuit configurations as illustrated in the block diagram shown in Figure 3 In general, they are divided into three main categories, namely shunt APF, series APF and hybrid APF.

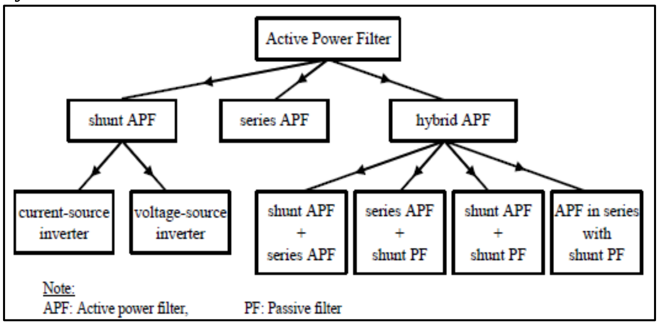

Fig. 3: Classification of active power filters

VII. SHUNT ACTIVE POWER FILTER

Shunt active power filter (SAPF) is commonly used as an effective method in compensating harmonic components in non-linear loads. Fig.4 shows the basic principle of SAPF in which APF is connected in parallel to the power system at a point of common coupling (PCC) between metropolitan electricity authority (MEA) and power users.

The objective of SAPF is to minimize the distortion in power supply using four main components – harmonic detection, compensating current control, DC bus voltage control, and active power filter – as shown in Fig.5 In the harmonic detection component, the distorted signal can be detected by several harmonic detection techniques, i.e., the instantaneous reactive power theory (PQ), the synchronous reference frame (SRF), the d-q axis with Fourier (DQF), and the synchronous detection (SD) etc. Then, APF injects the compensating currents into the power system.

The current control techniques are hysteresis current control, Pulse Width Modulation (PWM), and Space Vector Modulation (SVM) etc. For dc bus voltage control, proportional integral (PI) is employed. Commonly, APF uses 6 IGBT devices to build the voltage source inverter for injecting the compensation current to the system at PCC. The architecture of APF with IGBT device is shown in Fig.6.

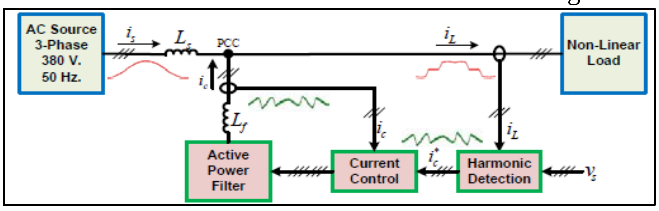

Fig. 4: The system using shunt active power filter

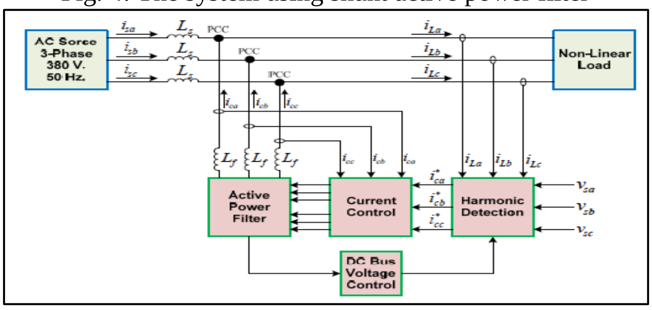

Fig. 5: Three – phase shunt active power filter

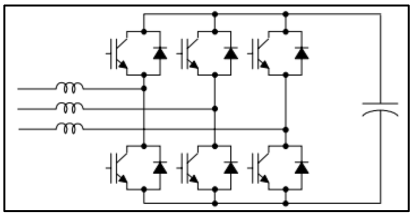

Fig. 6: Basic diagram for VSI

VIII. APF CONTROL STRATEGIES

A. *First Stage: Signal conditioning*

- Sensing system information by PT, CT, Isolation amplifiers
- Monitor, measure, record
- THD, power factor, active/reactive power, crest factor…

B. *Second Stage: Derivation of compensating signal*

- Current level and/or voltage level
- Frequency domain
- Based on Fourier transformation
- Cumbersome computation, large response time
- Time domain
- Based on instantaneous derivation pq theory, synchronous dq reference frame method, synchronous detection method, flux-based controller, notch filter method…

C. *Third stage: Generation of gating signal*

- Hysteresis, PWM, SVPWM, sliding mode, fuzzy-logic…

IX. COMPONENT CONSIDERATIONS OF APF

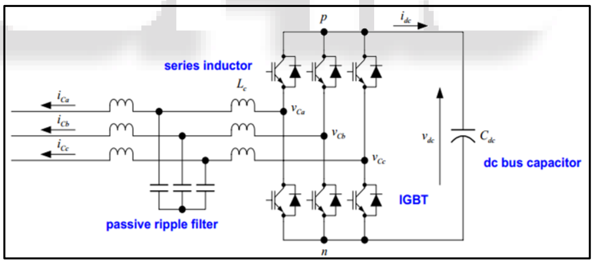

Fig. 7: Series inductor and passive ripple filter

- Series inductor: buffer between supply and PWM voltage
- Passive ripple filter: suppress switching harmonic and improve source THD
- DC bus capacitor: reduces dc ripples

X. BASIC CONCEPT OF ACTIVE FILTER CONTROL

A. *Active Filter as a Harmonic Canceller*

1) Harmonic Current Detection and Current Control Method”

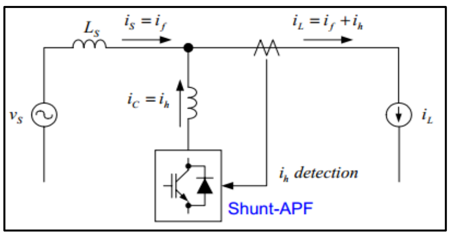

Fig. 8: Harmonic current detection and current control

2) Harmonic Voltage Detection and Voltage Control Method

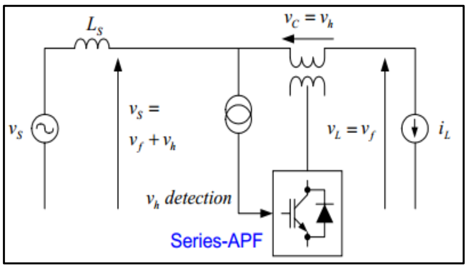

Fig. 9: Harmonic voltage detection and voltage control

B. *Active Filter as a Harmonic Damper*

1) Harmonic voltage detection and Current control method

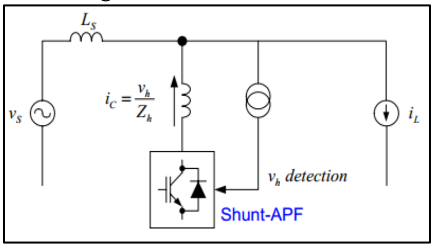

Fig. 10: Harmonic voltage detection And Current control

2) harmonic current detection and voltage control method

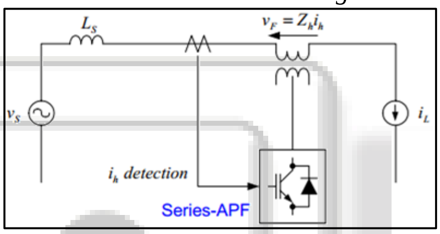

Fig 11: Harmonic current detection and voltage control

XI. CONCLUSION

Improved dynamic current harmonics and a reactive power compensation scheme for power distribution systems with generation from renewable sources has been proposed to improve the current quality of the distribution system. Advantages of the proposed scheme are related to its simplicity, modelling, and implementation. The use of a predictive control algorithm for the converter current loop proved to be an effective solution for active power filter applications, improving current tracking capability, and transient response. Simulated and experimental results have proved that the proposed predictive control algorithm is a good alternative to classical linear control methods. The predictive current control algorithm is a stable and robust solution.

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