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Simulation of Hybrid Series Active Filter for Household Application

Ritika Chaudhary[1]* Dr. Swati Sharma[2]

Abstract – In this paper a Multilevel Transformer less Hybrid Series Active Filter (Multilevel-THSeAF) is proposed to enhance the power quality of a single-phase residential household. The proposed topology reflects new trends of consumers towards electronic polluting loads and integration of renewable sources which in fact may lead to the scope of a reliable and sustainable supply. This paper contributes to improvement of power quality for a modern single-phase system and emphasis integration of a compensator with energy storage capacity to ensure a sustainable supply. A proportional resonant (PR) regulator is implemented in the controller to prevent current harmonic distortions of various non-linear loads to flow into the utility. The main significant features of the proposed topology include the great capability to correct the power factor as well as cleaning the grid simultaneously, while protecting consumers from voltage disturbances, sags, and swells during a grid perturbation. It investigates aspects of harmonic compensation and assesses the influence of the controller's choice and time delay during a real-time implementation. Combinations of analysis and experimental results performed on a laboratory setup are presented for validation.

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INTRODUCTION

Over the past few years, the enormous increase in the use of non-linear loads, arises many power quality issues like high current harmonics, voltage distortion and low power factor etc. on electrical grid (Sushree, et. al., 2016). Hence the proliferation of non-linear load in system generates harmonic currents injecting into the AC power lines. This distorted supply voltage and current causes malfunction of some protection devices, burning of transformers and motors, overheating of cables. Hence it is most important to install compensating devices for the compensation of harmonic currents and voltages produced due to nonlinear load. Traditionally, passive power filters have been used as a compensating device, to compensate distortion generated by constant non-linear loads. These filters are designed to provide a low impedance path for harmonics and maintaining good power quality with a simplest design and low cost. However, passive filters have some demerits like mistuning, resonance, dependence on the conditions of the power supply system and large values of passive component that leading to bulky implementations. Now-a-days, harmonic interference become an important issue in power system because of increasing demand of non-linear loads. Harmonic interference causes harmonic contamination. This harmonic contamination affects power utility in many aspects such as increase losses in power system, decrease power factor and causes malfunction in customer's equipment. Traditionally passive power filters (PPFs) are widely used to mitigate harmonic contamination... However, PPFs has huge drawbacks such as large in size, mistuning, resonance phenomenon etc. In the middle of 1940s the shunt active power filter is developed to overcome the drawbacks of PPFs. But the cost of active filter is very high because of its high rating. Due to the high cost the active filter is not preferable in large scale industries.

Henceforth, to avoid these drawbacks of active filter, a combined system of passive filter and active filter. Among all the topology of HAPF, HSAPF is suitable for compensation of both voltage as well as current harmonics and also for compensation of reactive power. HSAPF is also gives better performance for both type of non-linear load such as voltage-type harmonic load and current-type harmonic load. Voltage-type of harmonic load is defined as a 3-phase full bridge diode rectifier, consists of a dc capacitor of larger value is in parallel with the resistor in DC side. Current-type harmonic load is built up by 3-phase diode bridge rectifier, with inductor in series with the resistor in output side. The performance of HSAPF system is developed by choosing a proper reference compensating voltage. This research article employed pq-theory for reference generation process. This theory is applied for the generation of compensating voltage. Performance of proposed HSAPF with p-q control approach is found feasible for both current-type harmonic load and voltage type harmonic load. This reference voltage is directly depends on load voltages and source currents. Hysteresis voltage controller is used for switching pattern generation because it is easy in computational intensive and fast in implementation. The control strategy is important to enhance the performance of HSAPF. In reality, many articles for hybrid power filter have already proposed advanced techniques to reduce current harmonics created by these non-linear loads. In this paper a linear feedback-feed-forward controller is designed for hybrid power filter. But this controller is not easy for getting both steady-state and transient state performances with the linear control strategy because the dynamic model of HSAPF system contains multiplication terms of control inputs and state variables. Due to the non-linear characteristics of HSAPF, a sliding mode controller is presented in this paper. The sliding mode control is known as an appropriate control technique for controlling non-linear systems with uncertain dynamics and disturbances due to its order reduction property and low sensitivity to disturbances and plant parameter variations, which reduces the burden of the requirement of exact modeling. Furthermore, this sliding mode control also diminishes the complicacy of feedback control design by means of decoupling the system into individual subsystems of lower dimension. Because of these given properties, the implementation of sliding mode control can be found in the areas of power electronic switching devices.

BRIEF SURVEY OF EARLIER WORK

Sushree Diptimayee Swain, Pravat Kumar Rayand Kanungo Barada Mohanty [1] has studied that the degradation in power quality causes adverse economic impact on the utilities and customers. Harmonics in current and voltage are one of the most commonly known power quality issues and are solved by the use of hybrid series active power filter (HSAPF). In this paper, a new controller design using sliding modecontroller-2 is proposed to make the HSAPF more robust and stable. An accurate averaged model of three-phase HSAPF is also derived in this paper. The design concept of the robust HSAPF has been verified through simulation and experimental studies and the results obtained are discussed.

Narendra Babu P, Biswajit Kar, Biswajit Halder[2]had analyses that Nowadays with elevation of Technology, electrical power requirement is grow exponentially rate. So many instruments require quality power for their operation run continuously. The consumer appliances are demand for quality power. But due to some inner components and outer components the quality power distribution is pretentious to consumer's side. Difference in current, voltage and frequency quality of power problems occurs in power system network. The Power electronic converters are the main cause for power quality issues, because of their high switching characteristics.

Soumya Ranjan Das, Prakash. K. Ray and Asit Mohanty [3] has studied that the Improvement of power quality (PQ) has become an essential aspect in current situation of power system. Conventionally power quality improvement was done through passive filters, shunt filter and series filter but they suffer from problems like resonance, fixed compensation and other PQ problems. Therefore in order to eradicate these issues some hybrid combination of filters including passive and active power filter (APF) are used. This paper proposes an analysis and comparative study of two different schemes of hybrid active power filter (HAPF). HAPF is configured with the arrangement of series, passive and shunt filter.

Yang-Wen Wangl, Man-Chung Wongl and Chi-Seng Laml [4] has studied that Hybrid active power filter (HAPF) has already been an effective and widely-used method for power quality improvement. This paper presents historical review and developing progress of the HAPFs' functionalities as harmonic and reactive power compensation. The structures of HAPFs are discussed in different historical periods, and divided into four developing pattern: parallel active part with parallel element, parallel active part with series element, b-shape, and three-phase four-wire structure. It is aimed at making a comprehensive analysis of HAPFs' historical developing tendency in structure and function design.

Carlos H. da Silva, R. B. Gonzatti, S. C. Ferreira, R. R. Pereira, L. E. Borges da Silva, G. Lambert-Torres, Se Un Ahn[5] has describe that Hybrid active series power filters, as originally proposed, presents a way to improve the physical limitation of tuned passive filters. However these improvements are restricted to a single filter parameter: quality or tuned factor. To overcome these limitations, the active impedance has been proposed. By handling, at the same time, the quality and the tuned factor the topology is able to compensate multiple harmonic current just by using a single tuned passive filter. In this paper the details about active impedance concept are demonstrated. An appropriated control strategy based on PR Controller is used to implement the active filter complex gain.

POWER QUALITY ISSUES AND ITS CONSEQUENCES

Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or malfunctioning of customer equipment. Power quality is a two-pronged issue, with electronic equipment playing both villain and victim. Most new electronic equipment, while more efficient than its mechanical predecessors, consumes electricity differently than traditional mechanical appliances. Power supply quality issues and resulting problems are consequences of the increasing use of solid state switching devices, nonlinear and power electronically switched loads, electronic type loads .the advent and wide spread of high power semiconductor switches at utilization, distribution and transmission leaves have non sinusoidal currents.

SOURCES OF HARMONICS

Equipment using Power Electronic Devices

AC & DC Drives

Frequency Converters

Rectifiers or Inverters

Arc & Induction furnaces & ovens

UPS

Compact Fluorescent & other discharge Lamps

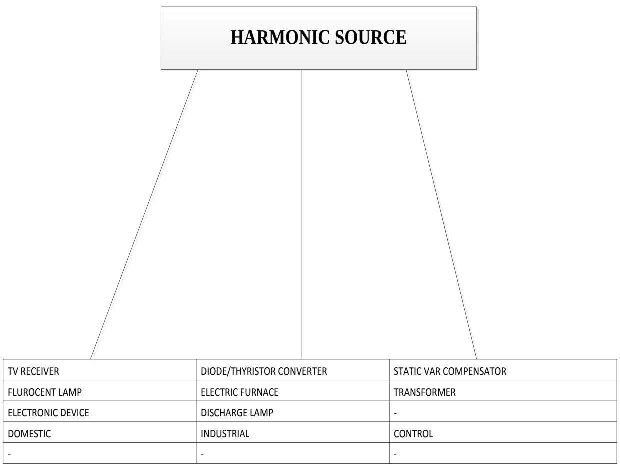

Figure 2.1: Harmonic source

HARMONIC SOURCES FROM INDUSTRIAL LOADS

Modern industrial facilities are characterized by the widespread application of nonlinear loads. These loads can make up a significant portion of the total facility loads and inject harmonic currents into the power system, causing harmonic distortion in the voltage. This harmonic problem is compounded by the fact that these nonlinear loads have a relatively low power factor. Industrial facilities often utilize capacitor banks to improve the power factor to avoid penalty charges.

The application of power factor correction capacitors can potentially magnify harmonic currents from the nonlinear loads, giving rise to resonance conditions within the facility. The highest voltage distortion level usually occurs at the facility's low voltage bus where the capacitors are applied. Resonance conditions cause motor and transformer overheating, and disoperation of sensitive electronic equipment. Nonlinear industrial loads can generally be grouped into three categories: three-phase power converters, arcing devices, and saturable devices.

EQUIPMENT USING SWITCHED MODE POWER SUPPLY

- Television
- Computers, other IT Loads

EFFECTS OF HARMONICS

- Problem caused by harmonics
- Over loading of neutral
- Overheating of neutral
- Nuisance tripping of circuit barker
- Skin effect
- Overheating of induction motor

Wave form distortion is generally discussed in terms of harmonic which are sinusoidal voltage or current having high frequency that are the multiple of the frequency at which supply system is design to operate when the frequency of this voltage & current are termed as inter harmonics. Harmonics in power distribution system are current or voltage that are integer multiples of fundamental frequency. For example if the fundamental frequency 50Hz, then 3rd is 150Hz, 5th is 250Hz. ideally, voltage and current waveforms are perfect sinusoids. However, because of the increased popularity of electronic and non-linear loads, these waveforms become distorted. This deviation from a perfect sine wave can be represented by harmonic components having a frequency that is an integral multiple of the fundamental frequency.

HYBRID SERIES ACTIVE POWER FILTER

The principle of sliding mode control is defined as to enforce the sliding mode motion in a predefined switching surfaces of the system state space using discontinuous control. The switching surfaces should be selected in such a way that sliding motion would maintain desired dynamics of motion according to certain performance criterion. The conventional control methods, such as Linear-quadratic regulator (LQR) or Linear quadratic Gaussian (LQG) servo controller for linear systems, are required to choose proper switching surfaces.

Then, the discontinuous control needs to be chosen such that any states outside of the discontinuity surface are enforced to reach the surface at finite time. Accordingly, sliding mode occurs along the surface, and the system follows the desired system dynamics.

The main difficulty of hardware implementation of classical sliding mode control method is chattering. Chattering is nothing but an undesirable phenomenon of oscillation with finite frequency and amplitude. The chattering is dangerous because the system lags control accuracy, high wear of moving mechanical parts, and high heat losses occurs in electrical power circuits. Chattering occurs because of unmodeled dynamics. These un-modeled dynamics are created from servomechanisms, sensors and data processors with smaller time constants. In sliding mode control the switching frequency should be considerably high enough to make the controller more robust, stable and no chattering because chattering reduces if switching frequency of the system increases. The application of sliding mode controller in power converter systems for example in HSAPF, a natural way to reduce chattering is increasing switching frequency. However, it is not possible in case of power converters because of certain limitations in switching frequency for losses in power converters, for which it results in chattering. Therefore, this chattering problem cannot blame sliding mode implementation since it is mainly caused by switching limitations. In this paper it is shown that the chattering exponentially tends to zero if the relative degree of the system with actuators or sensors is two. Difference in current, voltage and frequency power quality issues will occur in power system network [2], due to nonlinear load the deviation will comes in currents. If the power quality problem is in power system network, results appliances in network is damaged or sometimes failure. And efficiency and performance of equipment's reduced (Narendra, et. al., 2016).

To eliminate the harmonics and improve power quality, Hybrid Active Power Filter (HAPF) particularly shunt HAPF are introduced. Hybrid Active Power filters are the merge with Active and passive filters [2]. HAPF is merge with passive filter and active power filter (APF). Passive filters are used to filter out the selected harmonics, and passive filters have some disadvantages, they are parallel resonance, size of passive filter is more, filtering feature is constant so it pretentious by the source impedance, so to overcome these negatives the active power filters and HAPF are introduced (Narendra, et. al., 2016).

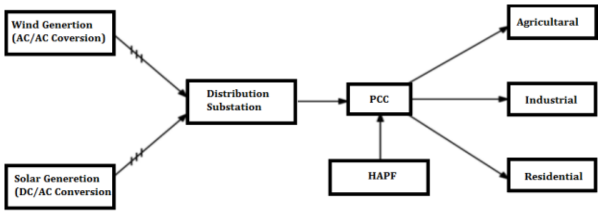

Fig. 3.1 Location of HAPF in Power system Network

This paper details about the modelling and analysis and comparative study of HAPF which is a combination of Shunt Passive Filter in series with active power filter, which the compensation currents are calculated using instantaneous reactive power theory and Fryze current compensation theories are implemented to reduce harmonics. Total Harmonic Distortion (THD) values under different loading conditions are listed and the MATLAB/SIMULINK results are presented.

The overall system incorporates an three phase AC source, with connected with Nonlinear load connected with RL load, PF, APF, three phase universal bridge, unbalanced resistive Load, Hysteresis Current controller, PI Controller. Using Instantaneous reactive power theory calculates real (p) and reactive power (q) using alpha beta transformation. For compensating currents calculation using Inverse Clark's transformation. These compensating currents are given input to the HCC. HCC generates the pulses to give filter inverter. Fig 3.1 shows location of HAPF. The overall structure of proposed system is shown in Fig 3.2.

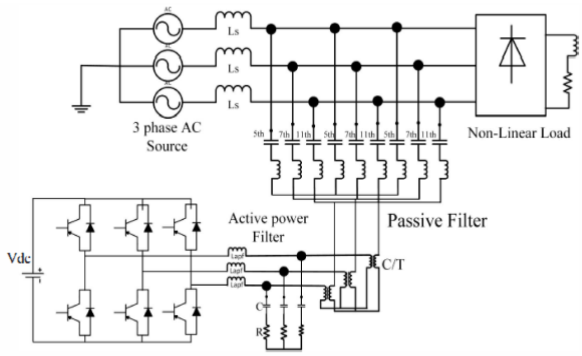

Fig 3.2- Block Diagram of Hybrid Active Power Filter

CONTROLLING OF HYBRID SERIES ACTIVE POWER FILTER

The relative degree of HSAPF system is two. Because of this relative degree of HSAPF system and also for these obstacles in classical sliding mode controller, this research paper proposed a new controller i.e. sliding mode controller-2. This proposed controller suppressed chattering and enhance the performance of HSAPF. This controller is completely new for this topology of HSAPF system.

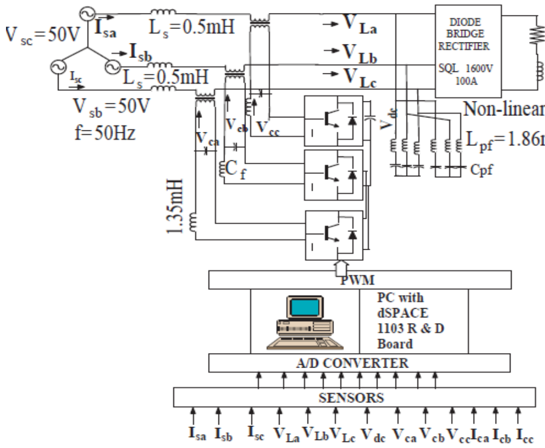

Fig. 3.3: Schematic diagram of the control and power circuit of HSAPF

The recent research work focuses on carrier based PWM (CBPWM) for HSAPF topology. But in some cases the CBPWM based HSAPF may not be completely measurable in most of the real-world situations. In case of CBPWM, power system perturbations have not been taken into consideration and also the presence of a time delay at the reference tracking point gives rise to a slow response of the overall system. Thus, tracking error is not reduced effectively and stability of the system is minimally improved. To overcome this, a SMC- 2 controller is proposed for voltage source converter (VSC). The idea behind this controller is to achieve gain stability, perfect tracking and distortion free current and load voltage. In view of above mentioned issues, we give more emphasis on the development of robust controller with a faster reference tracking approach in HSAPF, which permits all perturbations such as load voltage distortion, parametric variation of load, source current distortion and supply voltage unbalance so that compensation capability of the HSAPF system can be enhanced.

Fig.3.3 shows the schematic diagram of the control and power circuit of 3-phase HSAPF. The SAPF consists of a voltage source inverter connected to the grid through an LC filter and a three phase linear transformer. The series resistance of the inductors are neglected. Where, Va, Vb and Vc are the duty cycle of the inverter legs in a switching period, whereas Vca, Vcb, Vcc are the output voltage of series active filter for three phases are shown in Fig. 3.3 and Ica, Icb, Icc are known as the three phase current output of active filter, VaN, VbN, VcN are the phase voltages for three phases, Isa, Isb, Isc are known as the three phase source current, VnN is the neutral voltage.

MATLAB SIMULATION OF THREE PHASE SAPF SYSTEM

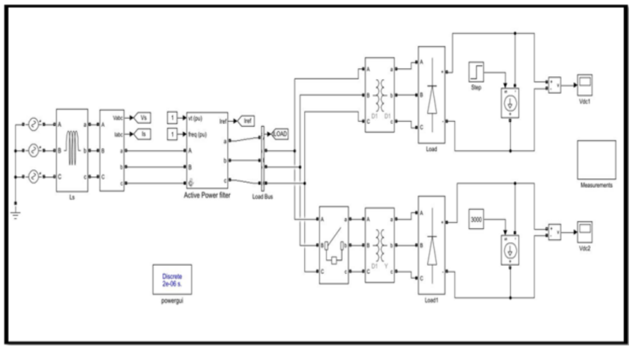

Fig 4.1 Matlab simulation of 3-phase APF system

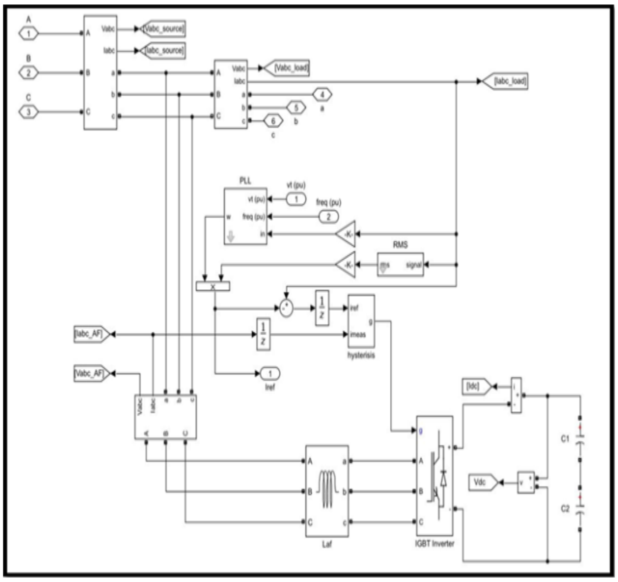

Fig 4.2 APF subsystem

Simulation Results

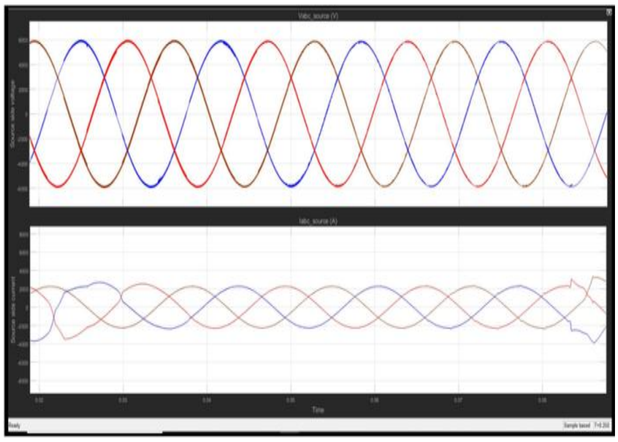

Fig 4.3 Source side voltage and current

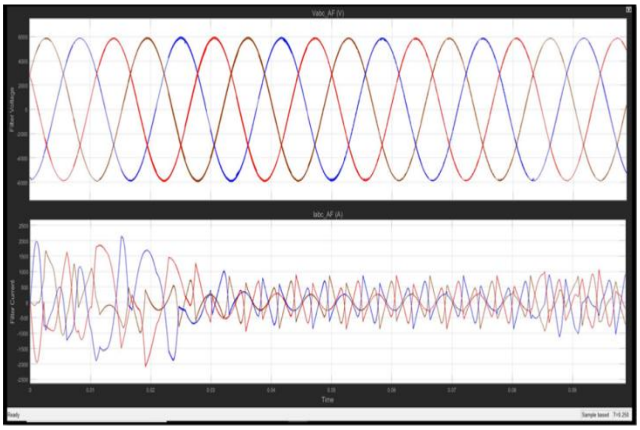

Fig 4.4 Filter side voltage and current

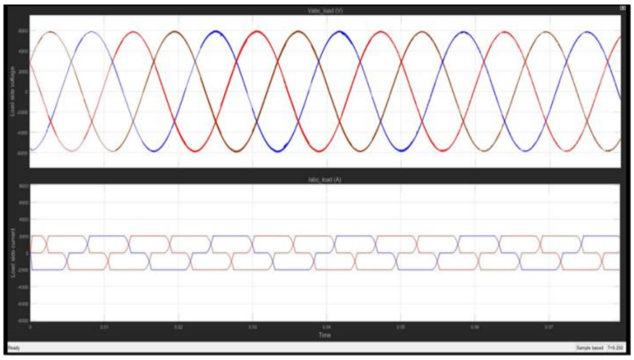

Fig 4.5 Load side voltage and current

CONCLUSION

In this paper a new robust controller design for HSAPF has been presented. The control design is established by sliding mode controller-2 that derives the equivalent control law. This control law is very much helpful for switching pattern generation. The robust- ness of the proposed controller has been verified by analyzing the performance under steady state as well as transient condition of the power system. In detail study about our topic we can conclude that the increased use of static power converter and static power capacitors can set up system condition to cause power quality problems like harmonics in power system. The proposed filter can compensate source currents and also adjust itself to compensate for variations in non-linear load currents, maintain dc link voltage at steady state and helps in the correction of power factor of the supply side adjacent to unity. In this paper we have design the Matlab simulation of Series APF for Voltage waveform improvement.

FUTURE WORK:-

One may extend this work in following aspects

- In the presence of an additive white noise, switching losses and distortion in both source current as well as load voltage, SRF method is found to be the best one for reference generation. Furthermore, the main feature of sliding mode controller-2 is the variable structure control method, which reduces tracking error distortion, suppress chattering, noise and hence a perfect gain stability of the HSAPF system has been achieved.
- The proposed filter can compensate source currents and also adjust itself to compensate for variations in non-linear load currents, maintain dc link voltage at steady state and helps in the correction of power factor of the supply side adjacent to unity.

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Corresponding Author

Ritika Chaudhary*

ritika.chaudhary@gmail.com