
## Faculty of Electrical Engineering

# DESIGN AND ANALYSIS OF A SERIES ACTIVE POWER FILTER BASED ON HYSTERESIS CONTROLLER FOR POWER QUALITY IMPROVEMENT

**Hadi Fakhir Hashim**

**Master of Electrical Engineering (Industrial Power)**

**2016**

# DESIGN AND ANALYSIS OF A SERIES ACTIVE POWER FILTER BASED ON HYSTERESIS CONTROLLER FOR POWER QUALITY IMPROVEMENT

**HADI FAKHIR HASHIM**

**A dissertation submitted**
**in partial fulfillment of the requirements for the degree of Master of Electrical Engineering (Industrial Power)**

**Faculty of Electrical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2016**

## DECLARATION

I declare that this research entitle "Design and analysis of a Series Active Power Filter Based on Hysteresis Controller for Power Quality Improvement" is the result of my own research except as cited in the references. The research has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Hadi Fakhir Hashim

Date : / /

## APPROVAL

I hereby declare that I have read this research and in my opinion this report is sufficient in terms of scope and quality as a partial fulfillment of Master of Electrical Engineering (Industrial Power).

Signature :

Supervisor Name : **Assoc. Prof. Ir. Dr. Rosli bin Omar**

Date : / /

**DEDICATION**

To my beloved parents, and my dear wife

## ABSTRACT

This dissertation presents the analysis and design of a three phase series active power filter based on hysteresis controller for power quality improvement. The proposed system comprises of a filtering scheme, injection transformer, Voltage Source Inverter (VSI) and its controller. The main aim of this dissertation covers design, analysis and modeling using MATLAB/SIMULINK for a three phase series active power filter. The system is capable of mitigating voltage sags and swells at low voltage distribution system. The proposed controller based on hysteresis controller was applied to the series active power filter throughout injected transformer. The implementation of hysteresis controller is capable to detect voltage disturbances in supply voltage and injects an appropriate voltage in order to recover decrease or an increase of supply voltage back to its nominal value, and then the load can be protected from any voltage disturbances. The connected load in the system consists of linear or nonlinear loads. The Total Harmonics Distortion (THD) values of current and voltage for linear and non-linear loads are measured. The various performances of simulation results of the proposed modeling has been investigated. Finally, the proposed system has successfully implemented in this research for mitigating voltage sags and swells. In addition, the voltage disturbance compensating performance of the Series Active Power Filter has improved using the hysteresis-control method.

## ABSTRAK

*Disertasi ini mempersembahkan analisa dan merekabentuk penapis kuasa aktif siri berdasarkan pengawal "hysterisis" untuk penambahbaikan kualiti kuasa. Sistem yang dicadangkan terdiri daripada skim penuras,pengubah suntikan, Punca Voltan Balikan(PVB) dan pengawalnya.Matlamat utama disertasi ini meliputi merekabentuk,analisa dan simulasi dengan menggunakan MATLAB/SIMULINK untuk penapis kuasa aktif siri. Sistem ini berkemampuan mencegah voltan runtuh dan voltan tambah dalam sistem pengagihan voltan rendah. Pengawal yang dicadangkan yang berdasarkan pengawal "hysteresis" dibekalkan padai penapis kuasa aktif siri melalui pengubah suntikan. Penggunaan pengawal "hysterisis" berkemampuan mengesan gangguan voltan dalam voltan bekalan dan menyuntik voltan secukupnya untuk memulihkan voltan bekalan kembali kepada voltan yang normal akibat dari voltan runtuh dan voltan tambah dengan ini dapat melindungi beban dari gangguan voltan.Beban tersambung dalam sistem terdiri dari beban linear dan beban tidak linear Jumlah Harmonik Penyelewengan (THD) diukur untuk arus dan voltan bagi beban linear dan beban tidak linear. Keputusan Simulasi dapat dihasilkan dari model yang dicadangkan. Akhirnya sistem yang dicadangkan berjaya diapplikasikan dalam kajian ini untuk mencegah voltan runtuh dan voltan tambah. Tambahan pula prestasi penapis kuasa aktif siri dalam mengatasi gangguan voltan dapat dipertingkatkan dengan menggunakan kaedah pengawal "hysteresis"*

## ACKNOWLEDGEMENTS

First and foremost, all praises and thanks to ALLAH, the almighty. Alhamdulillah, and peace and blessings of ALLAH be upon the last Prophet Mohamed S.A.W. I am ever grateful to HIS endless blessings throughout my research work which is the main reason behind the success for the completion of this research.

I would like to express my deepest gratitude and appreciation to Assoc. Prof. Ir. Dr. Rosli bin Omar, my supervisor, from Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for his encouragement, patience, and guidance during my study.

I am extremely grateful to my beloved parents for their love and prayers. I am also very much thankful to my wife for her love, understanding, prayers and continuing support to complete this research work. My sincere thanks to my family, my relatives, and friends who all gave me courage and support.

Finally, I am extending my thanks to all the people who have supported me to complete the research work directly or indirectly.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AC | - | Alternating Current |
| DC | - | Direct Current |
| EPQ | - | Electric Power Quality |
| APF | - | Active Power Filters |
| SAPF | - | Series active power filter |
| PAPF | - | Parallel Active Power filter |
| HAPFs | - | Hybrid active power filters |
| PHAPFs | - | Parallel hybrid active power filters |
| SHAPFs | - | Series hybrid active power filter |
| UPQC | - | Unified power quality conditioner |
| THD | - | Total Harmonic Distortion |
| THDv | - | Voltage Total Harmonic Distortion |
| IGBT | - | Insulated Gate Bipolar Transistor |
| GTO | - | Gate turn-off |
| PWM | - | Pulse Width Modulation |
| SPWM | - | Sinusoidal Pulse Width Modulation |
| Vdc | - | Voltage Direct Current |
| DVR | - | Dynamic voltage restorer |
| ASD | - | Adjustable speed drives |

IEEE STD - Institute of Electrical and Electronic Engineer standard

MLI - Multilevel Inverter Neutral

RMS - Root Mean Square

0 - Zero Sequence Component

1 - Positive Sequence Component

2 - Negative Sequence Component

## LIST OF SYMBOLS

| | | |
|---|---|---|
| pu | - | Per-Unit |
| $I_{fu}$ | - | The RMS value of the fundamental current component |
| $I_k$ | - | The RMS values of the harmonic current |
| $i_{lo,h}$ | - | Load current harmonics |
| *ipf,* | - | Compensation current |
| $i_{sup}$ | - | The sinusoidal supply current |
| $k$ | - | is the ordinal number of the highest harmonic |
| $u_{sf}$ | - | output voltage |
| $i_{sup,h}$ | - | the supply current harmonics |
| $v_b$ | - | Base Voltage in Three Phase System |
| $I_b$ | - | Base Current in Three Phase System |
| $V_{pu}$ | - | Per-Unit Voltage in Three Phase System |
| $I_{pu}$ | - | Per-Unit Current in Three Phase System |
| Z | - | Impedance |
| X | - | Reactance |
| $X_L$ | - | Load Reactance |
| R | - | Resistance |
| $R_L$ | - | Load Resistance |
| $R_s$ | - | Source Resistance |
| $R_T$ | - | Transformer Resistance |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Research

Power quality improvement has become a major research topic in modern power distribution system. Nearly twenty years ago most of the loads used by the industries and consumers were passive and linear in nature, with a lesser number of nonlinear loads thus having less impact on the power system. With the arrival of semiconductor and power electronic devices and their easier controllability have caused wide use of nonlinear loads such as chopper, inverter switched mode power supply, rectifier, etc. (Jena, 2014).

The distribution system is a vital joining between the generation and consumption of electrical power at rated amplitude and frequency, which indicates the Electric Power Quality (EPQ). EPQ is often used to express voltage as well as current quality, reliability of service, and quality of power supply, etc. Problems on power quality sources or (voltage disturbances in electrical distribution network) are raised up from two categories (Engineering, 2012):

i. Nonlinear loads, electrical components and tools.

ii. Subsystems of transmission and distribution systems. Quality degradation of electric power mainly occurs due to power line disturbances such as impulses, notches, voltage sags / swell, voltage and current unbalance, interruption and harmonic distortions. The electric power quality has become an important part of the distribution power system. Thus, harmonics are the primary cause for the poor power quality of the distribution system.

Power quality problems deals with a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient and interruptions. According to IEEE standard 1159-1995, a voltage sag is defined as a decrease in rms voltage down to 90% to 10% of nominal voltage for a time greater than 0.5 cycles of the power frequency but less than or equal to one minute-. Voltage sags have always been present in power systems, but only during the past decades have customers become more aware of the inconvenience caused by them. Voltage sag may be caused by switching operations associated with a temporary disconnection of supply(Std et al., 1995).

Voltage swell, on the other hand, is defined as an increase in rms voltage or current at the power frequency for durations from half a cycles to 1 min, typical magnitudes are between 1.1 and 1.8 p.u. Voltage sags are the most severe power quality problem in distribution system while voltage swells are not as important as voltage sags because they are less common in distribution systems. Voltage sag and swell can cause sensitive equipment to shut down or fail, as well as create a large voltage and current unbalances that could blow fuses or trip breakers. These effects can be very expensive for the customer, ranging from minority quality variations to production downtime and equipment damage (Tripti Shahi, 2014) .

Harmonics are a mathematical way of describing distortion to a voltage or current waveform. The term harmonic refers to a component of a waveform that occurs at an integer multiple of the fundamental frequency (Ellis and Eng, 2001).

Harmonics are caused by nonlinear loads that are loads that draw a non-sinusoidal current from a sinusoidal voltage source. Some examples of harmonic producing loads are electric arc furnaces, static VAR compensators, inverters, DC converters, switch-mode power supplies, and AC or DC motor drives.

Voltage Fluctuations are described by IEEE as systematic variations of the voltage waveform envelope, or a series of random voltage changes, the magnitude of which falls between the voltage limits set by ANSI C84.1. Generally, the variations range from 0.1% to 7% of nominal voltage with frequencies less than 25 Hz. Subsequently, the most important effect of this power quality problem is the variation in the light output of various lighting sources, commonly termed as Flicker. This is the impression of instability of the visual sensation brought about by a light stimulus, whose luminance fluctuates with time.

Power quality problems mitigated using compensators. The power filters dealt within this research are divided into passive filters, active power filters (APFs). The APFs are divided into parallel active power filter (PAPF) and series active power filter (SAPF),-. and unified power quality conditioner (UPQC).

## 1.2 **Motivation of Research**

In AC voltage, supply from utility always occurs a problem due to voltage disturbance in electrical network which leads to drop voltage. These types of voltage disturbance are sag, swell, harmonic, transient voltage. AC power supply provides different kinds of linear and nonlinear loads. The nonlinear loads such as power converters and solid state drives that use “high speed switches” are the main sources of voltage disturbance in voltage distributions in electrical network.

The voltage disturbance in the system induce some undesirable issues; such as “increased heating in transformers, low power factor, torque pulsation in motors, overvoltage by resonance, and harmonic voltage drop across the network impedance”. This scenario needs to investigate or propose a new mitigation device to developed distributions system.

Recently, Active Power Filter (APFs) are developed for compensating the voltage disturbance and reactive-power simultaneously in voltage distributions in electrical network. The series APF works as a voltage regulator and harmonic isolator between the nonlinear load and distribution network. The series active filter injection voltage component in series with the supply voltage, therefore can be regarded as a control voltage source, compensating voltage sag and swell on the load side. The injected harmonic voltages are added or subtracted to or from the source voltage to maintain pure sinusoidal voltage through the load.

## 1.3 **Problem Statements**

At the present time, AC power supply is used as a main supply for operating system. Therefore, it will be a problem if the AC supply is not in its original condition due to the voltage disturbance generated by the load specially a device which is attached by the power electronic circuits. In recent years, both residential and industrial load in distribution system include electronic devices which is considered as non-linear load that has been increased significantly. These non-linear loads are the major source of voltage disturbance such as a sag, swell and harmonics which are making the distribution system polluted. On the other hand, the modern equipment is becoming increasingly sophisticated and requires clean power for its proper operation. Any disturbance in supply voltage, such as voltage sag and swell or even harmonics in voltage causes the sensitive equipment to malfunction.

To solve this problem and improve the quality of power, voltage disturbance filter (series active power filters) is needed in order to remove this voltage disturbance from the supply systems. These compensators have proven as an important and flexible alternative to compensate most important voltage and current related power quality problems in the distribution system. The other alternative is the use of a unified power quality conditioner