DESIGN OF UNIFIED POWER QUALITY CONDITIONER (UPQC) FOR POWER QUALITY IMPROVEMENT

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NFC INSTITUTE OF ENGINEERING AND
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DESIGN OF UNIFIED POWER QUALITY CONDITIONER (UPQC) FOR POWER QUALITY IMPROVEMENT

This project has been prepared by the students of electrical engineering of session 2010-2014 who have been allotted the given project by electrical engineering department in order to fulfil the requirement of their

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Undertaking

We certify that project work titled “DESIGN OF UPQC FOR POWER QUALITY IMPROVEMENT” is our own work. No portion of the work presented in this project has been submitted in support of another award or qualification either at this institution or elsewhere. Where material has been used from other sources it has been properly acknowledged / referred.

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Abstract

Power quality (PQ) problem can be defined as the deviations of the voltage And/or current from the nominal sine wave. P-Q problems generally concern with voltage sags/swells and harmonic currents. Custom Power (CP) devices that mitigate these power quality problems have gained more attention in the recent decades. Unified Power Quality Conditioner (UPQC) is one of the CP devices and it mitigates both load current and supply voltage problems, simultaneously.

UPQC is Designed, modelled and setup experimentally to mitigate voltage sag/swells and harmonic currents. UPQC consists of Dynamic Voltage Restorer (DVR) and Active Power Filter (APF). Traditional Instantaneous Reactive Power Theory (IRPT) is optimized for APF control algorithm to compensate harmonic load current under unbalanced and distorted supply voltages. UPQC with proposed controller algorithms effectively compensates the sag/swell in supply voltage by keeping the load voltage amplitude at 0.9-1 per unit and eliminates the load current harmonics by keeping supply current at 5% less than of Total Harmonic Distortion, simultaneously.

UPQC can work in zero active power consumption mode, active power absorption mode and active power delivering mode. The series active power filter (APF) part of UPQC works in active power delivering mode and absorption mode during voltage sag and swell condition, respectively. The shunt APF part of UPQC during these conditions helps series APF by maintaining dc link voltage at constant level.

It is found that the UPQC in Three-phase system effectively compensates the important power quality issues, such as the load reactive power, load current harmonics, voltage harmonics, voltage sag, voltage swell and voltage flicker.

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INTRODUCTION

1.1 Introduction to Unified Power Quality Conditioner (UPQC)

Power Quality (PQ) has become an important issue to electricity consumers at all levels of usage. The PQ issue is defined as “Any power problem manifested in voltage, current, or frequency deviations that results in failure or disoperation of customer equipment.” The development of power electronic based equipment has a significant impact on quality of electric power supply. The switch mode power supplies (SMPS), dimmers, current regulator, frequency converters, low power consumption lamps, arc welding machines, etc., are some out of the many vast applications of power electronics based devices. The operation of this loads/equipment generates harmonics and thus, pollutes the modern distribution system. The growing interest in the utilization of renewable energy resources for electric power generation is making the electric power distribution network more susceptible to power quality problems. In such conditions both electric utilities and end users of electric power are increasingly concerned about the quality of electric power.

Many efforts have been taken by utilities to fulfil consumer requirement, some consumers require a higher level of power quality than the level provided by modern electric networks. This implies that some measures must be taken so that higher levels of Power Quality can be obtained.

Active power filters (APF) have been proposed as efficient tools for power quality improvement. Active power filters can be classified as series or shunt according to their system configuration. The series APF generally takes care of the voltage based distortions, while shunt APF mitigates current based distortions. The combination of series and shunt active power filter is called the unified power-quality compensator (UPQC). UPQC mitigates the voltage and current based distortion simultaneously as well as independently. In this thesis the main focus is on UPQC.

1.2 Project Overview

UPQC is design to improve power quality of 3 phase and 4 wire system. It is the combination of software and hardware. Basically our block diagram has following major blocks:

- Source
- Isolation Transformer
- 3 phase IGBT Driver circuit.
- IGBT Modules.
- PIC Microcontroller
- 3 phase load 5-6 KW
- AC and DC Supply

1.3 Block Diagram

Figure 1.1: Block Diagram of UPQC

1.3.1 Description of block diagram

Our focus is on the design UPQC based power quality conditioner through which we will control the three phase power problems like harmonics, power factor, voltage sag/swell, reactive power compensation.

With the help of PIC microcontroller PWM pulses generate and fed to the IGBT Drive circuit which in turns drives the IGBT modules. IGBT will be implemented as a soft-start of high-power equipment and provides pure sine wave consistently. During fault conditions the IGBT will operate to clear the fault for a maximum duration of 1.5 seconds. IGBT work on zero reactive power compensation modes.

The hardware will evolve into a PCB for the finished schematic. Finally, the whole circuit will be powered supply to make it energy efficient.

1.4 Project Objective

A Unified Power Quality Conditioner – UPQC results from the joint operation of a series active conditioner and a shunt active conditioner. The UPQC aggregates in single equipment the current compensation capabilities of a shunt active power filter and the voltage compensation capabilities of a series active filter, allowing the mitigation of both current- and voltage-related problems simultaneously.

- Compensation of voltage harmonics;
- Compensation of voltage unbalance;
- Compensation of voltage sags;
- Compensation of voltage swells;
- Compensation of current harmonics;
- Elimination of the neutral current;
- Correction of the power factor.

1.5 Problem Statement

With the wide application of nonlinear and electronically switched devices in distribution systems, the power quality problem becomes more serious Harmonics, Voltage Sag and Swell, Poor power Factor and Lower Efficiency.

Conventional methods to solve these problems are DVR and DSTATCOM for the mitigation of Voltage sag and swell. Passive filters were used to remove Harmonic. For Power Factor Improvement Capacitors Bank Synchronous motors were used.

Traditionally based, passive L-C filters were used to eliminate line harmonics. However, the passive filters have the demerits of fixed compensation, bulkiness and occurrence of resonance with other elements.

POWER QUALITY

2.1 Definition of power quality

Power quality has different meanings to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment”. There is a broad range of power quality problems associated with power systems based on time such as long duration variations, short duration variations and other disturbances. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems.

The main reasons for concern with power quality (PQ) are as following:

- End user devices become more sensitive to PQ due to many microprocessor-based controls.
- Large computer systems in many businesses facilities.
- Power electronics equipment used for enhancing system stability, operation and efficiency. These are major sources of bad Power Quality.
- Continuous development of high-performance equipment: Such equipment is more susceptible to power disturbances.

The users always demand higher power quality. Some basic criteria for power quality are constant rms value, constant frequency, symmetrical three-phases, pure sinusoidal wave shape and limited THD.

2.2 Responsibilities of the suppliers and users of electrical power

The realization of quality electrical power is the responsibility of the suppliers and users of electricity. Suppliers are in the business of selling electricity to widely varying client. The need of one user is usually not the same as the needs of other users. Most electrical equipment is designed to operate within a voltage of $\pm 5\%$ of nominal with marginal decrease in performance. For the most part, utilities are committed to adhering to these limits. At locations remote from substations

supplying power from small generating stations, voltages outside of the $\pm 5\%$ limit are occasionally seen. Such variation could have a negative impact on loads such as motors and fluorescent lighting. The overall effects of voltage outside the nominal are not that significant unless the voltage approaches the limits of $\pm 10\%$ of nominal. Also, in urban areas, the utility frequencies are rarely outside ± 0.1 Hz of the nominal frequency. This is well within the operating tolerance of most sensitive.[1]

TABLE 2.1 Immunity and Power Quality Indices [1]

Index	Description	Examples
Equipment Immunity Indices		
I	High immunity	Motors, transformers, incandescent lighting, heating loads, electromechanical relays
II	Moderate immunity	Electronic ballasts, solid-state relays, programmable logic controllers, adjustable speed drives
III	Low immunity	Signal, communication and data processing equipment, electronic medical equipment
Power Quality Indices		
I	Low power quality problems	Service entrance switchboard, lighting power distribution panel
II	Moderate power quality problems	HVAC power panels
III	High power	Panels supplying adjustable speed drives, elevators, large motors

2.3 Sources of Poor Power Quality

Sources of poor Power Quality are listed as follows:

- Adjustable –speed drives
- Switching Power supplies
- Arc furnaces
- Electronic Fluorescent lamp ballasts
- Lightning Strike
- L-G fault

- Non- linear load
- Starting of large motors
- Power electronic devices

2.4 Need of Power Quality

There is an increased concern of power quality due to the following reasons:

1. New-generation loads that use microprocessor and microcontroller-based controls and power electronic devices, are more sensitive to power quality variations than that equipment used in the past.
2. The demand for increased overall power system efficiency resulted in continued growth of devices such as high-efficiency adjustable-speed motor drives and shunt capacitors for power factor correction to reduce losses. This is resulting in increasing harmonic level on power systems and has many people concerned about the future impact on system capabilities.
3. End users have an increased awareness of power quality issues. Utility customers are becoming better informed about such issues as interruptions, sags, and switching transients and are challenging the utilities to improve the quality of power delivered.
4. Most of the networks are interconnected these days. Integrated processes mean that the failure of any component has much more important consequences.[1]

2.5 Classification of Power Quality Problems

2.5.1 Short Duration Voltage Variation

Depending on the fault location and the system conditions, the fault can cause either temporary voltage drops (sags), voltage rises (swells), or a complete loss of voltage (interruptions). The duration of short voltage variations is less than 1minute. These variations are caused by fault conditions, the energization of large loads which require high starting currents, or intermittent loose connections in power wiring.

2.5.1.1 Voltage Sag

Voltage sag (also called a “dip”) is a brief decrease in the rms line voltage of 10 to 90 percent of the nominal line-voltage. The duration of a sag is 0.5 cycle to 1 minute. Common sources that contribute to voltage sags are the starting of large induction motors and utility faults.

Figure 2.1: Voltage Sag[1]

2.5.1.2 Voltage Swell

A swell is a brief increase in the rms line-voltage of 110 to 180 percent of the nominal line-voltage for duration of 0.5 cycle to 1 minute. The main sources of voltage swells are line faults and incorrect tap settings in tap changers in substations.

Figure 2.2: Voltage Swell[1]

2.5.1.3 Interruption

An interruption is defined as a reduction in line-voltage or current to less than 10 percent of the nominal, not exceeding 60 seconds in length. Interruptions can occur due to power system faults, equipment failures and control malfunctions.

Figure 2.3: Interruption[1]

2.5.2 Long-Duration Voltage Variation

Long-duration variations can be categorized as over voltages, under voltages or sustained interruptions.

2.5.2.1 Overvoltage

An overvoltage is an increase in the rms ac voltage greater than 110 percent at the power frequency for duration longer than 1 min. Over voltages are usually the results of load switching or incorrect tap settings on transformers.

2.5.2.2 Under voltage

An under voltage is decreases in the rms ac voltage to less than 90 percent at the power frequency for duration longer than 1 min. A load switching on or a capacitor bank switching off can cause an under voltage until voltage regulation equipment on the system can restore the voltage back to within tolerance limits. Also overloaded circuits can result in under voltage.

2.5.2.3 Sustained Interruptions

When the supply voltage has been zero for a period of time in excess of 1 min the long-duration voltage variation is considered a sustained interruption.[2]

2.5.3 Transients

2.5.3.1 Impulsive Transient

An impulsive transient is a brief, unidirectional variation in voltage, current, or both on a power line. Lightning strikes, switching of inductive loads, or switching in the power distribution system are the most common causes of impulsive transients. The effects of transients can be mitigated by the use of transient voltage suppressors such as Zener diodes.

Figure 2.4: Impulsive Transients[2]

2.5.3.2 Oscillatory Transient

An oscillatory transient is a brief, bidirectional variation in voltage, current, or both on a power line. These are caused due to the switching of power factor correction capacitors.

Figure 2.5: Oscillatory Transients[2]

2.5.4 Voltage Fluctuations

Voltage fluctuations are relatively small (less than 5 percent) variations in the rms line voltage.

Figure 2.6: Voltage Fluctuations or Flicker [2]

Cyclo-converters, arc furnaces, and other systems that draw current not in synchronization with the line frequency are the main contributors of these variations.

2.5.5 Voltage Imbalance

A voltage imbalance is a variation in the amplitudes of three-phase voltages, relative to one another. Voltage imbalance can be the result of different loads on the phases, resulting in different voltage drops through the phase-line impedances.

Figure 2.7: Voltage imbalance [2]

2.5.6 Waveform Distortion

Waveform distortion is defined as a steady-state deviation from an ideal sine wave of power frequency principally characterized by the spectral content of the deviation.

(i) DC offset: The presence of a dc voltage or current in an ac power system is termed dc offset.

2.5.7 Harmonics

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate, and that is known as the fundamental frequency which is usually 50 or 60 Hz. The harmonic distortion originates in the nonlinear characteristics of devices and also on loads connected to the power system.

Figure 2.8: Harmonics [2]

Harmonic distortion levels can be described by the calculating total harmonic distortion (THD) which measures the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. THD is represented as the square-root of the sum of the squares of each individual harmonic. Voltage THD is

$$V_{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1}$$

Where V_1 is the rms magnitude of the fundamental component, and V_n is the rms magnitude of component n where $n = 2, \dots, \infty$. The problem with this approach is that THD become infinity if no fundamental is present. A way to avoid this ambiguity is to use an alternate definition that represents the harmonic distortion. This is called the distortion index (DIN) and is defined as

$$DIN = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{\sqrt{\sum_{n=1}^{\infty} V_n^2}}$$

THD and DIN are interrelated by the following equations

$$DIN = \frac{THD}{\sqrt{1+THD^2}}$$

$$THD = \frac{DIN}{\sqrt{1-DIN^2}}$$

2.5.7.1 Sub-harmonics

Sub harmonics can be defined as frequency components in voltage and current waveforms less than the power system frequency. Cyclo-converters, adjustable speed drives, arc furnaces, wind generators and other loads inject low frequency currents that produce sub harmonic distortion in voltage supply.

2.5.7.2 Inter-harmonics

Voltages or currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate (50 or 60 Hz) are called inter-harmonics. Inter-harmonics can appear as discrete frequencies or as a wideband spectrum. The main sources of inter-harmonic waveform distortion are static frequency converters, induction furnaces, cyclo-converters and arcing devices. Power line carrier signals can also be considered as inter-harmonics.[3]

2.5.8 Electrical Noise

Noise is a high frequency distortion of the voltage waveform. Caused by disturbances on the utility system or by equipment such as welders, switchgear and transmitters, noise can frequently go unnoticed. Frequent or high levels of noise can cause equipment malfunction, overheating and premature wear.

Figure 2.9: Electrical Noise Waveform [3]

2.5.9 Notching

Notching is a disturbance of opposite polarity to the normal voltage waveform (which is subtracted from the normal waveform) lasting for less than one-half cycle. Notching is usually caused by malfunctioning of electronic switches or power conditioners. While it is generally not a major problem, notching can cause equipment, especially electronics, to operate improperly.

Figure 2.10: Notching Waveform[3]

2.6 Solutions to Power Quality Problems

The mitigation of power quality problems can be achieved in two ways. It can be done from either customer side or utility side. First approach used is load conditioning and the other is line conditioning. Load conditioning ensures that the equipment is less sensitive to power disturbances. They are based on PWM converters and connected in shunt or in series to low and medium voltage distribution system. Series active power filters operate in conjunction with shunt passive filters in order to compensate load current harmonics. Series active power filters operates as a controllable voltage source whereas shunt active power filters operate as a controllable current source. Both of these schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. However, with the restructuring of power sector, the line conditioning systems or utility side solutions will play a vital role in improving the inherent supply quality. Some of the effective and economic measures can be identified as following: [3]

2.6.1 Lightning and Surge Arresters

Arresters are designed for lightening protection of transformers, but are not sufficient for limiting voltage fluctuations to protect sensitive electronic control circuits.

2.6.2 Thyristor Based Static Switches

The static switch is a device for switching a new element into the circuit when the voltage support is needed. It has a dynamic response time of about one cycle. It can be used in the alternate power line applications. To correct quickly for voltage spikes, sags or interruptions, the static switch can be used to switch one or more of devices such as filter, capacitor, alternate power line, energy storage systems etc.

2.6.3 Energy Storage Systems

Storage systems can be used to protect sensitive equipment from shutdowns caused by voltage sags or momentary interruptions. Energy is fed to the system to compensate for the energy that would be lost by the voltage sag or interruption. The systems used are usually DC storage systems such as batteries, UPS,

superconducting magnet energy storage (SMES), storage capacitors or even fly wheels driving DC generators. The output of these devices can be supplied to the system through an inverter on a momentary basis.

2.6.4 Electronic Tap Changing Transformer

A voltage-regulating transformer with an electronic load tap changer can be used with a single line from the utility. It can regulate the voltage drops up to 50% and requires a stiff system (short circuit power to load ratio of 10:1 or better).

2.6.5 Harmonic Filters

Filters are used where effective reduction or elimination of certain harmonics is required. If possible, it is always preferable to use a 12-pulse or higher transformer connection, rather than a filter. Usually, multiple filters are needed, each tuned to a separate harmonic. Each filter causes a parallel resonance as well as a series resonance, and each filter slightly changes the resonances of other filters. [3]

2.7 Custom power devices

2.7.1 Introduction

For improving the system performance for distribution system and with the growing development of the power semiconductor technology, the concepts of custom power were introduced to distribution systems. The concept describes the value-added power that electric utilities will offer their customers in the future, focusing on the quality of power flow and reliability. Due to this increasing demand and the rapid development of the high-power semiconductor technology, the custom power solutions are taking place rapidly. In a custom power system customer receives specified power quality from a utility or a service provider or at-the-fence equipment installed by the customer in coordination with the utility, which includes an acceptable combination of the following features:

- No (or rare) power interruptions
- Magnitude and duration of voltage reductions within specified limits.
- Low harmonic voltage.
- Low phase unbalance.

This can be done on the basis of an individual, large customer, industry or a supply for a high-tech community on a wide area basis.

2.7.2 Need of Custom Power

The increased use of automated equipment, like adjustable speed drives, programmable logic controllers, switching power supplies, arc furnaces, electronic fluorescent lamp ballasts, automated production lines are far more vulnerable to disturbances than were the previous generation equipment and less automated production and information systems.

Even though the power generation in most advanced country is fairly reliable, the distribution is not always so. It is however not only reliability that the consumers want these days, quality too is very important for them. With the deregulation of the electric power energy market, the awareness regarding the quality of power is increasing day by day among customers. Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage.

In the several processes such as semiconductor manufacturing or food processing plants, a batch of product can be ruined by a voltage dip of very short duration. Even short dips are sufficient to cause contactors on motor drives to drop out. There are other loads which are very sensitive such as hospitals, processing plants, air traffic control and numerous other data processing and service providers that require clean and uninterrupted power. Thus, in this scenario in which customers increasingly demand power quality, the term power quality attains increased significance.

The factors mentioned point out the problems faced by the industry and awareness of consumers about quality of power due to which it has increasingly become important to provide the consumers with the reliable as well as superior power quality. Thus, the development of custom power has gained so much of widespread attention nowadays. [4]

2.7.3 Custom Power Devices

There are many types of Custom Power devices. Some of these devices include Active Power Filters (APF), Surge Arresters (SA). Battery Energy Storage Systems

(BESS), Super conducting Magnetic Energy Systems (SMES), Static Electronic Tap Changers (SETC), Solid State Fault Current Limiter (SSFCL), Solid-State Transfer Switches (SSTS), Static VAR Compensator (SVC), Distribution Series Capacitors (DSC), Dynamic Voltage Restorer (DVR), Distribution Static synchronous Compensators (DSTATCOM) and Uninterruptible Power Supplies (UPS) , Unified power quality conditioner(UPQC).

The classification of custom power devices can be done into two major categories, one is network configuring type and the other is compensating type. The network configuring type devices changes the configuration of the power system network for power quality enhancement. SSCL (Solid State Current Limiter), SSCB (Solid State Circuit Breaker) and SSTS (Solid State Transfer Switch) are the most representative in this category.

The compensating type devices are used for active filtering; load balancing, power factor correction and voltage regulation. The family of compensating devices includes DSTATCOM (Distribution Static compensator), DVR (Dynamic voltage restorer) and Unified power quality conditioner (UPQC). DSTATCOM is connected in shunt with the power system while DVR is a series connected device that injects a rapid series voltage to compensate the supply voltage. UPQC is the combination of DSTATCOM and DVR. It injects series voltage and shunt currents to the system.

Though there are many different methods to mitigate voltage sags and swells, but the use of a custom power device is considered to be the most efficient method to serve for different purposes. The term Custom Power pertains to the use of power electronic controllers in a distribution system to deal with various power quality problems. It makes sure that customers get pre-specified quality and reliability of power supply that may include a single or the combination of the specifications like no power interruptions, low phase unbalance, low harmonic distortion in load voltage, low flicker at the load voltage, acceptance of fluctuations, magnitude and duration of overvoltage and under voltages within specified limits and poor factor loads without significant effect on the terminal voltage. [4]

2.7.4 Solid State Current Limiter

The most widely used solution for limitation of the fault currents is to use a transformer with a split secondary winding (or a three windings transformer) and current limiting reactors. The basic configuration of Solid-State Current Limiter is shown in Figure 2.1. However, the usage of fault current limiting reactors with powerful motor loads has a negative impact on the stability of motors, for example when short-term voltage sags occur. It would be worthwhile to directly control transients, resulting from faults, at primary circuits, thus alleviating effects of the faults.

Series fault current limiters used to limit the fault current by disconnecting solid-state switch and increasing the impedance. However, such scheme has a disadvantage: the system should be operating in continuous mode, and malfunction of the static switch could lead to interruption of power supply for the customer.

Parallel fault current limiters are activated only at the moment of fault and have the following functions:

- limit the peak fault current
- decrease the motors feeding into the fault
- shunt the consumer switches while disconnecting

Figure 2.11: Solid state current limiter[5]

2.7.5 Solid State Transfer Switch

The SSTS can be used very effectively to protect sensitive loads against voltage sags, swells and other electrical disturbances. The SSTS provides continuous high-quality power supply to sensitive loads by transferring, within a time scale of milliseconds, the load from a faulted bus to a healthy one. The basic configuration of this device consists of two three-phase solid-state switches, one for the main feeder another for the backup feeder. These switches have an arrangement of back-to-back connected thyristors, as illustrated in the schematic diagram of Fig. 2.12.

Each time a fault condition is detected in the main feeder, the control system swaps the firing signals to the thyristors in both switches, i.e., Switch 1 in the main feeder is deactivated and Switch 2 in the backup feeder is activated. The control system measures the peak value of the voltage waveform at every half cycle and checks whether or not it is within a pre specified range. If it is outside limits, an abnormal condition is detected and the firing signals to the thyristors are changed to transfer the load to the healthy feeder.[5]

Figure 2.12: Solid state transfer switch. [5]

The success of the SSTS is mainly due to its rather low cost compared with other solutions. A requirement is that a secondary in-feed, independent from the main source (e.g. a feeder to another substation), must be available. Therefore, this solution is particularly attractive for installations that already have mechanical transfer systems, where upgrading to a static system does not require major changes in the layout of the distribution system. Formerly available only for low voltages,

SSTS systems are now advertised for higher voltages and load ratings, which make them suitable for high-power industrial applications. Transfer-time estimation of a SSTS is not a straightforward process due to its dependence on commutation between the thyristor switches in each phase. The commutation is determined by the system parameters and the component characteristics. To offer ride-through capability, the load must be transferred within the shortest possible time. [5]

2.7.6 Active Power Filters

The increasing use of power electronics-based loads (adjustable speed drives, switch mode power supplies, etc.) to improve system efficiency and controllability is increasing the concern for harmonic distortion levels in end use facilities and on the overall power system. The application of passive tuned filters creates new system resonances which are dependent on specific system conditions.

Passive filters often need to be significantly overrated to account for possible harmonic absorption from the power system. Passive filter ratings must coordinate with reactive power requirements of the loads and it is often difficult to design the filters to avoid leading power factor operation for some load conditions.

Active filters have the advantage of being able to compensate for harmonics without fundamental frequency reactive power concerns. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor.

Active power filters can perform one or more of the functions required to compensate power systems and improving power quality. The rating of the active power can be less than a conquerable passive filter for the same nonlinear load and the active filter will not introduce system resonances that can move a harmonic problem from one frequency to another. [6]

2.7.7 Distribution Static Compensator (DSTATCOM)

The purpose of the DSTATCOM is to cancel load harmonics fed to the supply. The coupling of DSTATCOM is three phases, in parallel to network and load. It works as current sources, connected in parallel with the nonlinear load, generating the harmonic currents the load requires also balance them in addition to providing reactive power. In order to compensate undesirable components of the load current the DSTATCOM injects currents into the point of common coupling. With an appropriated control strategy, it is also possible to correct power factor and unbalanced loads. This principle is applicable to any type of load considered a harmonic source.

Figure 2.13: Distribution Starcom (DSTATCOM) [6]

Its advantage is that it carries only the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. Shunt Active Power Filter in current control mode is also called as DSTATCOM.

2.7.8 Dynamic Voltage Restorer (DVR):

Figure 2.14: Dynamic Voltage Restorer (DVR) [6]

DVR injects a voltage component in series with the supply voltage, thus compensating voltage sags and swells on the load side. Control response is on the order of 3msec, ensuring a secure voltage supply under transient network conditions. Voltage injection of arbitrary phase with respect to the load current implies active power transfer capability. This active power is transferred via the dc link, and is supplied either by a diode bridge connected to the ac network, a shunt connected PWM converter or by an energy storage device. It works as a harmonic isolator to prevent the harmonics in the source voltage reaching the load in addition to balancing the voltages and providing voltage regulation. [6]

2.7.9 Unified Power Quality Conditioner (UPQC)

The best protection for sensitive loads from sources with inadequate quality, is shunt-series connection i.e. unified power quality conditioner (UPQC) .Recent research efforts have been made towards utilizing unified power quality conditioner (UPQC) to solve almost all power quality problems for example voltage sag, voltage swell, voltage outage and over correction of power factor and unacceptable levels of harmonics in the current and voltage The basic configuration of UPQC is shown in fig.2.15.

The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected as one of the most powerful solutions to large capacity sensitive loads to voltage flicker/imbalance.

Unified Power Quality Conditioner (UPQC) for non-linear and a voltage sensitive load has following facilities:

- It eliminates the harmonics in the supply current, thus improves utility current quality for nonlinear loads.

- UPQC provides the VAR requirement of the load, so that the supply voltage and current are always in phase, therefore, no additional power factor correction equipment is necessary.
- UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag.
- The voltage injected by UPQC to maintain the load end voltage at the desired value is taken from the same dc link, thus no additional dc link voltage support is required for the series compensator.

The UPQC consists of two three phase inverters connected in cascade in such a manner that Inverter I is connected in series with the supply voltage through a transformer inverter II is connected in parallel with the load. The main purpose of the shunt compensator is to compensate for the reactive power demanded by the load, to eliminate the harmonics and to regulate the common dc link voltage. The series compensator is operated in PWM voltage-controlled mode. It injects voltage in quadrature advance to the supply voltage (current) such that the load end voltage is always maintained at the desired value. The two inverters operate in a coordinated manner.

Figure 2.15: Unified Power Quality Conditioner (UPQC) [6]

There are three principle elements to the custom power concept; these are:

- The Dynamic Voltage Restorer (DVR), it provides series compensation by voltage injection for power system sag and swell.

- The Distribution Static Compensator (D-STATCOM), it provides continuously variable shunt compensation by current injection for eliminating voltage fluctuations and obtaining correct power factor in three-phase systems. An ideal application of it is to prevent disturbing loads from polluting the rest of the distribution system.
- Unified Power Quality Conditioner (UPQC), it provides series and shunt compensation i.e. inject voltage in sag and swell condition and inject current for elimination of voltage fluctuations, correct power factor, avoid pollution to rest of the distribution system.
- The proper selection of necessary custom power strategies in addition to accurate system modeling and appropriate protection devices will increase the power quality.

2.8 Superiority of UPQC over Other Devices

Each of Custom Power devices has its own benefits and limitations. The UPQC is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage and load current disturbances /imbalance. The most effective type of these devices is considered to be the Unified Power Quality Conditioner (UPQC). There are numerous reasons why the UPQC is preferred over the others. UPQC is much flexible than any single inverter-based device. It can simultaneously correct for the unbalance and distortion in the source voltage and load current whereas all other devices either correct current or voltage distortion. Therefore, the purpose of two devices is served by UPQC only. [6]

LITERATURE REVIEW

3.1 Literature Review of Unified Power Quality Conditioner

Power quality issues are becoming more and more significant in these days because of the increasing number of power electronic devices that behave as nonlinear loads. A wide diversity of solutions to power quality problems is available for both the distribution network operator and the end user. The power processing at supply, load and for reactive and harmonic compensation by means of power electronic devices is becoming more prevalent due to the vast advantages offered by them. The shunt APF is usually connected across the loads to compensate for all current related problems such as the reactive power compensation, power factor improvement, current harmonic compensation and load unbalance compensation, whereas the series active power filter is connected in a series with a line through series transformer. It acts as controlled voltage supply and can compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc. UPQC is a Custom Power device and consists of combined series active power filter that compensates voltage harmonics, voltage unbalance, voltage flicker, voltage sag/swell and shunt active power filter that compensates current harmonics, current unbalance and reactive current as shown in Figure 3.1.

Figure 3.1: Basic representation of UPQC

The Unified Power Quality Conditioner is a custom power device that is employed in the distribution system to mitigate the disturbances that affect the performance of sensitive and/or critical load. It is a type of hybrid APF and is the only versatile device which can mitigate several power quality problems related with voltage and current simultaneously therefore is multi functioning devices that compensate various voltage disturbances of the power supply, to correct voltage fluctuations and to prevent harmonic load current from entering the power system. Figure shows the system configuration of a single-phase UPQC. Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. The shunt converter is connected in parallel to the load. It provides VAR support to the load and supply harmonic currents. Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply. Thus, UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor. [7]

Figure 3.2: Block diagram of UPQC [7]

3.2 Basic configuration of UPQC

The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers.

3.2.1 Series converter

It is a voltage-source converter connected in series with the AC line and acts as a voltage source to mitigate voltage distortions. It is used to eliminate supply voltage

flickers or imbalance from the load terminal voltage and forces the shunt branch to absorb current harmonics generated by the nonlinear load. Control of the series converter output voltage is usually performed using sinusoidal pulse-width modulation (SPWM). The gate pulses required for converter are generated by the comparison of a fundamental voltage reference signal with a high-frequency triangular waveform.

3.2.2 Shunt converter

It is a voltage-source converter connected in shunt with the same AC line and acts as a current source to cancel current distortions, compensate reactive current of the load, and improve the power factor. It also performs the DC-link voltage regulation, resulting in a significant reduction of the DC capacitor rating. The output current of the shunt converter is adjusted using a dynamic hysteresis band by controlling the status of semiconductor switches so that output current follows the reference signal and remains in a predetermined hysteresis band. [7]

3.2.3 Midpoint-to-ground DC capacitor bank

It is divided into two groups, which are connected in series. The neutrals of the secondary transformers are directly connected to the DC link midpoint. As the connection of both three-phase transformers is Y/Yo, the zero-sequence voltage appears in the primary winding of the series-connected transformer in order to compensate for the zero-sequence voltage of the supply system. No zero-sequence current flows in the primary side of both transformers. It ensures the system current to be balanced even when the voltage disturbance occurs.

3.2.4 Low-pass filter

It is used to attenuate high frequency components at the output of the series converter that are generated by high-frequency switching

3.2.5 High-pass filter

It is installed at the output of shunt converter to absorb current switching ripples.

3.2.6 Series and shunt transformers

These are implemented to inject the compensation voltages and currents, and for the purpose of electrical isolation of UPQC converters. The UPQC is capable of steady-state and dynamic series and/or shunt active and reactive power compensations at fundamental and harmonic frequencies. However, the UPQC is only concerned about the quality of the load voltage and the line current at the point of its installation, and it does not improve the power quality of the entire system. [8]

3.3 Equivalent single-phase representation of the UPQC

The equivalent single-phase representation of the UPQC in a power distribution system is shown in Fig. 3.3. The distorted supply voltage v_s at the point of common coupling is modelled by the sum of two voltage sources, namely, its fundamental v_{sf} and its harmonics v_{sh} . The nonlinear load is modelled by a distorted current source i_L , which is also made up of its fundamental i_{Lf} and its harmonics i_{Lh} that will change with different loadings. The supply current and the load voltage are denoted by i_s and v_L , respectively.

Figure 3.3: Equivalent single-phase representation of the UPQC[8]

Ideally, i_s and v_L should be sine waves of 50 Hz without any harmonic distortions, even though harmonics may exist in v_s and i_L . As such, this is one of the tasks to be accomplished by the UPQC. v_z in Fig.3.3 models the voltage drop across the line impedance $R_l + j\omega L_l$. $u_1(V_{dc}/2)$ and $u_2(V_{dc}/2)$ model the series and shunt active

filters of the UPQC, respectively. Their associated low-pass interfacing filters and losses are modelled by L_{se} , C_{se} , and R_{se} , and L_{sh} , C_{sh} , and R_{sh} , respectively. i_{Csh} is the leakage capacitor current of the shunt low-pass interfacing filter. $u_1(V_{dc}/2)$ and $u_2(V_{dc}/2)$ represent the switched voltages across the series and shunt VSI outputs of the UPQC, respectively. v_{inj} denotes the injected voltage of the series active filter, while i_{inj} denotes the injected current of the shunt active filter. u_1 and u_2 will be determined by the ORC to be discussed later; they are supposed to take continuous values between -1 and $+1$. These continuous values will be modulated by PWM to become the switching signals for the VSIs. $V_{dc}/2$ is the desired voltage level of each capacitor unit for the UPQC. [8]

3.4 Functions performed by UPQC

- Convert the feeder (system) current into balanced sinusoids through the shunt compensator.
- Convert the load voltage V_L to balanced sinusoids through the series compensator.
- Ensure zero real power injection (and/or absorption) by the compensators.
- Supply reactive power to the load (Q compensation).

UPQC is also known as the universal power quality conditioning system, universal active power line conditioner and universal active. UPQC system can be divided into two sections: The control unit and the power circuit. Control unit includes disturbance detection, reference signal generation, gate signal generation and voltage/current measurements. Power circuit consists of two voltage source converters, standby and system protection system, harmonic filters and injection transformers. The findings of the comprehensive literature survey summarize the available studies related with control unit and power circuit of UPQC. [8]

3.5 Power Circuit Topologies of UPQC

UPQC is a combination of a shunt (Active Power Filter) and a series compensator (Dynamic Voltage Restorer) connected together via a common DC link capacitor, which facilitates the sharing of the active power. Each compensator consists of IGBT inverters, which can be operated in current or voltage-controlled mode. Depending upon the location of the shunt compensator with respect to series compensator, UPQC model can be named as right shunt-UPQC or left shunt-UPQC. Typically, the active power generated in one unit is consumed in the other unit maintaining the energy balance overall characteristics of the right shunt-UPQC are superior to those of the left shunt-UPQC. Basic topologies of UPQC are shown in Figure 3.4.

Figure 3.4: Various power circuit topologies: (a) Left shunt-UPQC, (b) Right shunt-UPQC, (c) OPEN UPQC, (d) Interline UPQC and (e) Multilevel UPQC [9]

UPQC can be used for medium voltage and low voltage applications. In case of low power applications, it is not convenient to install a UPQC, since DVR spends most of its time in standby mode. UPQC is generally designed as 3-phase 3-wire (3P3W) systems. 3-phase 4-wire (3P4W) system is also realized from (3P3W) system where the neutral of series transformer used in series part UPQC is considered as the fourth

wire for 3P4W system. There are also single-phase UPQC systems. Various topologies such as multilevel topology, single-phase UPQC with two half-bridge converters, H bridge topology and single-phase UPQC with three legs are the examined for UPQC applications. A new topology consists of the DC/DC converter and the super capacitor is presented in. The series and parallel units do not have a common DC link in Advanced renewable generation based distributed power generation system is developed in UPQC is connected between two independent feeders to regulate the bus voltage of one of the feeders while regulating the voltage across a sensitive load in the other feeder in a new configuration, named multi converter unified power quality conditioner (MC-UPQC), for simultaneous compensation of voltage and current in adjacent feeders has been proposed in. Compared to a conventional UPQC, MC-UPQC topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell and interruption in two-feeder systems. The protection of a UPQC against voltage surges and short circuit conditions to prevent its malfunction or destruction is discussed in.

The power circuit of UPQC generally consists of common energy storage unit, DC/AC converter, LC filter and injection transformer. DC link (energy storage unit) supplies required power for compensation of load voltage during voltage sag/swell or current harmonics. UPQC generally consists of two voltage source inverters (series and shunt) using IGBT which operate from a common DC link storage capacitor. DC link (DC-DC converter) connected to the battery energy storage system is used in. Voltage interruption can also be eliminated by the use of a UPQC with distributed generation. Split capacitor topology is used in. Photovoltaic generation as well as the functions of a unified power quality conditioner is presented in. VSIs are preferred for both shunt and series sides. The series converters are generally composed of 6 bridges VSI and rarely composed of three single-phase H Bridge VSIs. Shunt converters are generally composed of 6 bridge VSIs for three-phase. There are also some studies using 6 bridge inverters for series converter and three single-phase H bridge inverters for shunt converter. Current source inverters are preferred for both shunt and series sides in. The effect of harmonics generated by the inverter can be minimized using inverter side and line side filtering. Inverter side LC filtering is generally preferred for both series sides and inverter side L filtering is generally preferred for shunt side. Inverter side C filtering is preferred for shunt side in. UPQC

incorporating an LCL filter is presented in. Series converter of UPQC is most of time in standby mode and conduction losses will account for the bulk of converter losses during the operation. In this mode, the series injection transformer works like a secondary shorted current transformer using bypass switches delivering utility power directly to the load. A novel configuration of UPQC which can be connected to the distribution system without series injection transformers is presented in. [9]

3.6 Control Techniques of UPQC Topologies

The control unit is the most important part of UPQC system. Rapid detection of disturbance signal with high accuracy, fast processing of the reference signal and high dynamic response of the controller are the prime requirements for desired compensation. The main considerations for the control system of a UPQC include (Figure 3.5):

- Series inverter control: Sag/swell detection, voltage reference generation, voltage injection strategies and methods for generating of gating signals.
- Shunt inverter control: Current reference generation, methods for generating of gating signals and capacitor voltage control.

Figure 3.5: Control unit of UPQC with a specified power circuit topology[9]

3.7 UPQC in Service and Future Trends

Digital controller based UPQC has been developed for a laboratory prototype in some of the studies. As a large-scale structure, a 250kVA UPQC is developed at Centre for the Development of Advanced Computing, Trivandrum, India and is under field trial at the centre. Hykon Group Company installs IGBT based UPQC in the range of 10kVA to 250kVA connected to a low voltage level.

Most of the proposed or practiced control strategies for power quality conditioners have been reviewed with regard to performance and implementation. The research reveals that there has been a significant increase in interest of UPQC and associated control methods. This can be attributed to the availability of suitable power-switching devices at affordable price as well as new generation of fast computing devices. However, deregulation of electricity market may contribute to rising penetration level of distributed generation from renewable energy sources (e.g. wind, solar, biomass, etc.) in the near future. This can lead to an increase in the number of UPQC studies based on distributed generation. [9]

3.8 Summary

Widespread applications of power electronic based devices/equipment in industry have increased the importance and application of power quality studies. Decrease in the cost of power electronic devices and improvement in the efficiency of both power converters and energy storage components have increased the applicability of new technological solutions such as Custom Power devices. CP devices including DVR, APF and UPQC are showing tremendous development. These devices have become very popular in recent years in both low voltage and medium voltage applications. The comprehensive reviews of articles concerning CP devices are presented to show the advantages and disadvantages of each possible configuration and control techniques. The literature survey reveals that new control algorithms and topologies for CP devices have been developed to minimize the power losses, increase the system flexibility and efficiency. These reviews will help the researchers to select the optimum control strategy and power circuit configuration for their CP applications.

HARDWARE DESCRIPTION

4.1 Hardware components

- Comparator IC (LM-339 N)
- NE 555 Timer IC
- L-7812 IC
- Relay (HRSS4H-S-12VDC)
- Potentiometer
- General Purpose Relays
- MOSFET Drivers (HCF-4047BE)
- MOSFET (CTC-313)
- IGBT Modules (QM100HY-H)
- Series Transformer (2 KVA)
- PIC Microcontroller (16F877A)
- IC 817C
- 7805 IC
- CT,PT
- Protection Fuses

4.1.1 Comparator IC (LM-339 N)

The LM139 series consists of four independent precision voltage comparators with an offset voltage specification as low as 2 mV max for all four comparators. These were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. These comparators also have a unique characteristic in that the input common-mode voltage range includes ground, even though operated from a single power supply voltage.

Application areas include limit comparators, simple analogue to digital converters; pulse, square wave and time delay generators, wide range VCO, MOS clock timers, multi vibrators and high voltage digital logic gates. The LM139 series was designed to directly interface with TTL and CMOS. When operated from both plus and minus power supplies, they will directly interface with MOS logic — where the low power drain of the LM339 is a distinct advantage over standard comparators.

Connection Diagram

Advantages

- High precision comparators.
- Eliminates need for dual supplies.
- Allows sensing near GND.
- Compatible with all forms of logic.
- Power drain suitable for battery operation.

4.1.2 NE 555 Timers IC

The 555-timer used as the circuit of Mono Stable, Multi Vibrator or Delay circuit with operating environment that provides a second output level be the voltage is low (logic “0”) and high-level voltage (logic “1”). When you click the switch S1 pin 2 of the IC will be shot down ground. The motive for the IC1 with low voltage (logic “0”) Resulting in the output pin 3 of IC voltage levels at higher or equivalent supply It makes light LED1. Experience in the scheduling itself And in setting up or slow down time depends on the R2, C1. And VR1 to adjust the scheduling easier.

Pin Description

Pin No	Function	Name
1	Ground (0V)	Ground
2	Voltage below $1/3 V_{cc}$ to trigger the pulse	Trigger
3	Pulsating output	Output
4	Active low; interrupts the timing interval at Output	Reset
5	Provides access to the internal voltage divider; default $2/3 V_{cc}$	Control Voltage
6	The pulse ends when the voltage is greater than Control	Threshold
7	Open collector output; to discharge the capacitor	Discharge
8	Supply voltage; 5V (4.5V - 16 V)	Vcc

555 timer as Mono-stable delay unit

4.1.3 LM-7812 IC

3-Terminal 1A Positive Voltage Regulator

The LM78XX series of three terminal positive regulators are available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut down and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and current.

Pin Configuration

4.1.4 Relay (HRSS4H-S-12VDC)

Nominal Voltage of this relay is 3 VDC to 48 VDC. Nominal Power Consumption for this type of relay is 360 to 450 mW. Contact Material is AgCd. HRS4H-S DC12V relay coil nominal VDC voltage 12 Volts. Operating voltage is 9 volts. Release voltage is 1.20 VDC.

Contact Rating

- 10A 120VAC / 24 VDC
- 15A 120VAC / 24 VDC

Max. Switching Voltage 110 VDC / 240 VAC Max. Switching Current 15A. Max. Switching Power 1800 VA, 360W. Contact Resistance (Initial) 50 m Ω at 6 VDC 1A. Expected life of this relay is Electrical 100,000 operations at nominal load. Mechanical 10,000,000 operations at nominal load. Dielectric Strength of this relay is 750VAC for 1min between open contacts. 1,500VAC for 1min between contacts and coil. Operate Time Max. 8ms. Release Time Max. 5ms. Temperature Range is -30 to +85. Vibration Resistance is 10 - 55 Hz.

4.1.5 Potentiometer

A potentiometer informally a pot is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat.

A potentiometer measuring instrument is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle, hence its name.

Potentiometers are commonly used to control electrical devices such as volume controls on audio equipment. Potentiometers operated by a mechanism can be used as position transducers, for example, in a joystick. Potentiometers are rarely used to directly control significant power (more than a watt), since the power dissipated in

Models with lockable test buttons are available. Many variations possible through a selection of operation indicators (mechanical and LED indicators), lockable test button, built-in diode and CR (surge suppression), bifurcated contacts etc. Arc barrier is standard on 4-pole Relays. Coil to contact Dielectric strength is 2,000 VAC. Environment-friendly cadmium-free contacts. Safety standard approved. Wide range of Sockets (PY, PYF Series) and optional parts are available.

PYF14A-E Relay Socket

4.1.7 HCF-4047B-E

It is Low power consumption mono-stable (one-shot) or Astable (free-running) multi-vibrator special. It provides true and complemented buffered Outputs. It requires only one external R and C for its operation. Quiescent current is specified to 20V for HCC devices. It provides standardized, symmetrical output Characteristics 5v, 10v, and 15v are the parametric ratings. Input current of 100nA at 18v and 25°C for HCC devices and 100% tested for quiescent current it also meets all requirements of standard specifications.

Pin Configuration

4.1.8 CTC-313

It is Small size IGBT with low forward voltage drop and high switching speed. Tail current is quite low and it is latch-up free.

4.1.9 IC-817C

Pin Configuration

- 1. Anode
- 2. Cathode
- 3. Emitter
- 4. Collector

4.1.10 4.4 Regulator LM7805

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. LM7805 receives almost 8 V from the output of the filter capacitor and is connected to the V_{in} Pin and the ground of the LM7805 respectively and we get regulated 5 V from V_{out} Pin and Ground.

4.2 PIC Micro-controller (16F877)

A microcontroller is a small computer on a single circuit containing a processor core, memory, and programmable input/output peripherals. Neither program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general-purpose applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analogue components needed to control non- digital electronic systems.

Some microcontrollers may use four-bit words and operate at clock rate frequencies as low as 4 kHz, for low power consumption (mill watts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping (CPU clock and most peripherals off) may be just nano watts, making many of them well suited for long lasting battery applications.

Other microcontrollers may serve performance-critical roles, where they may need to act more like a digital signal processor (DSP), with higher clock speeds and power consumption.

Microcontrollers and microprocessors are integrated circuits, but they differ fundamentally from other ICs. They are a class in themselves, that the designers have not made them to do a particular job. As such when you buy them from the market, you can not specify what function it will do. In order to get some useful function, these ICs have to be configured.

Thus, a microprocessor or microcontroller can be configured to check the status of a button, and then turn a motor ON or OFF. While the same IC can be configured later, to read the status of an infra-red sensor, decode the signal and turn another device ON or OFF.

If these two types of circuitries were to be made using conventional digital ICs, it would have required a large number of components. Moreover, any change in the specification, like change of Infra-Red codes would result in total change in design! Using a configurable IC is a great idea. Not only the same IC can be configured to do different tasks, but a change in specifications can easily be implemented by just changing the device configuration.

4.2.1 PIC16F877A

In our project we are using the PIC16F877A microcontroller for intelligent circuitry. We have chosen this controller due to its:

- Cost effectiveness.
- High-performance
- Built-in clock
- low-voltage
- Flexibility

Peripheral Features

- Timer0: 8-bit timer/counter
- Timer1: 16-bit timer/counter
- Timer2: 8-bit timer/counter
- Operating speed: DC – 20 MHz clock input
- Up to 8K x 14 words of Flash Program Memory
- Up to 368 x 8 bytes of Data Memory (RAM),
- Up to 256 x 8 bytes of EEPROM Data Memory
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI)

- Parallel Slave Port (PSP) – 8 bits wide with external RD, WR and CS controls

Analog Features

- 10-bit, up to 8-channel Analog-to-Digital Converter (A/D)

Special Microcontroller Features

- Self-reprogrammable under software control
- In-Circuit Serial Programming™ (ICSP™) via two pins
- Single-supply 5V In-Circuit Serial Programming
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code protection
- Power saving Sleep mode
- Selectable oscillator options
- In-Circuit Debug (ICD) via two pins
- Enables you to view variable values, Special Function Register and EEPROM while the program is running.

Pin Configuration

Figure 4.1: Pin configuration of PIC16F877A

4.2.1.1 I/O Ports of PIC16F877A

Some pins for these I/O ports are multiplexed with an alternate function for the peripheral features on the device.

I/ O pins there are 40 pins on PIC16F877A. Most of them can be used as an IO pin.

Others are already for specific functions. These are the pin functions.

1. MCLR – to reset the PIC
2. RA0 -port A pin 0
3. RA1 -port A pin 1
4. RA2 -port A pin 2
5. RA3 -port A pin 3
6. RA4 -port A pin 4
7. RA5 -port A pin 5
8. RE0 -port E pin 0
9. RE1 -port E pin 1
10. RE2-port E pin 2
11. VDD- power supply
12. VSS- ground
13. OSC1- connect to oscillator
14. OSC2- connect to oscillator
15. RC0 - port C pin 0
16. RC1 - port C pin 0
17. RC2 - port C pin 0
18. RC3 - port C pin 0
19. RD0 - port D pin 0
20. RD1 - port D pin 1
21. RD2 - port D pin 2
22. RD3 - port D pin 3
23. RC4 - port C pin 4
24. RC5 - port C pin 5
25. RC6 - port C pin 6
26. RC7 - port C pin 7
27. RD4 - port D pin 4
28. RD5 - port D pin 5

- 29. RD6 - port D pin 6
- 30. RD7 - port D pin 7
- 31. VSS - ground
- 32. VDD- power supply
- 33. RB0 - port B pin 0
- 34. RB1 - port B pin 1
- 35. RB2 - port B pin 2
- 36. RB3 - port B pin 3
- 37. RB4 - port B pin 4
- 38. RB5 - port B pin 5
- 39. RB6 - port B pin 6
- 40. RB7 - port B pin

There are five ports on PIC16F877A

- Port A
- Port B
- Port C
- Port D
- Port E

PORT A

- 6-bit wide, bidirectional port.
- Data direction register is TRISA.
- If TRISA=1 then PORTA input port vice versa.
- Pin PA4 is multiplexed with Timer0 module clock input to become the PA4/TOCK1 pin.
- Other PORTA pins are multiplexed with Analog input.
- On power reset these pins are analog input.

PORT B

- 8-bit wide, bidirectional port.
- Data direction register is TRISB.
- If TRISB=1, then PORTB is input else output.

- Three pins RB3/PGM, RB6/PGC and RB7/PGD are multiplexed with in circuit debugging and low voltage programming function.
- RB0/INT is an external interrupt pin and is configured using then INTEDG bit
- OPTION_REG<6>.

PORT C

- PORTC is 8-bit wide, bidirectional port.
- Data direction register is TRISC.
- RC0/T1OSO/T1CKI
- Input/output port pin
- Timer1 oscillator output
- Timer1 clock input.
- RC1/T1OSI/CCP2
- Input/output port pin
- Timer1 oscillator input
- PWM2 output.
- RC2/CCP1
- Input/output port pin
- PWM1 output
- RC3/SCK/SCL
- RC3 can also be the synchronous serial clock for SPI mode.
- RC4/SDI
- RC4 can also be the SPI data in (SPI mode)
- RC5/SDO
- Input/output port pin
- Synchronous Serial Port data output.
- RC6/TX/CK
- Input/output port pin
- USART asynchronous transmit
- Synchronous clock.
- RC7/RX/DT

- Input/output port pin
- USART asynchronous receive
- Synchronous data

PORT D

- 8-bit wide port.
- This port can be I/O or Parallel Slave Port.

PORT E

- Three pins port.
- The PORT E pins become the I/O control inputs for the microprocessor port when bit PSPMODE (TRISE<4>) is set.
- RE0/RD/AN5
 - I/O port pin
 - Read control input in Parallel Slave Port mode
 - analog input
- RE1/WR/AN6
 - I/O port pin
 - write control input in Parallel Slave Port mode
 - analog input
- RE2/CS/AN7
 - I/O port pin
 - chip select control input in Parallel Slave Port mode
 - analog input
 - PORTE pins are multiplexed with analog inputs

4.2.1.2 Basic connectivity of microcontroller

In order to enable the microcontroller to operate properly it is necessary to provide:

- a. Power Supply;
- b. Reset Signal; and
- c. Clock Signal.

Figure 4.2: Basic Microcontroller Connectivity

a. Power Supply

Even though the PIC16F877 can operate at different supply voltages, 5V DC power supply is the most suitable. The circuit, shown in figure 4.6, uses a cheap integrated three-terminal positive regulator LM7805 and provides high-quality voltage stability and quite to enable the enough current microcontroller.

b. Reset Signal

In order that the microcontroller can operate properly, a logic one (VCC) must be applied on the reset pin. The push button connecting the reset pin MCLR (master clear) to GND is not necessary. However, it is almost always provided because it enables the microcontroller to return safely to normal operating conditions if something goes wrong. By pushing this button, 0V is brought to the pin, the microcontroller is reset and the program execution starts from the beginning.

Figure 4.3: Reset to controller

c. Clock Signal

Even though the microcontroller has a built-in oscillator, it cannot operate without external components which stabilize its operation and determine its frequency which is operating speed of the microcontroller.

4.2.1.3 Analog-To-Digital Converter (A/D) Module

The Analog-to-Digital (A/D) Converter module has eight for the 40/44-pin devices. The conversion of an analogue input signal results in a corresponding 10-bit digital number. The A/D module has high and low-voltage reference input that is software selectable to some combination of VDD, VSS, RA2 or RA3.

The A/D module has four registers. These registers are:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)

The ADCON0 register controls the operation of the A/D module. The ADCON1 register configures the functions of the port pins. The port pins can be configured as analog inputs (RA3 can also be the voltage reference) or as digital I/O.

Figure 4.4: A/D Block Diagram

4.2.1.4 5V Regulated Power Supply

Figure 4.5: 5V Regulated Power Supply

Main Components include in 5V regulated power supply are:

- Transformer (220/12V)
- Bridge Rectifier
- Filter Capacitor
- Regulator LM7805 and LM7812

These are briefly described as under:

A *transformer* is a device that transfers electrical energy from one circuit to another through inductively coupled conductors the transformer's coils. A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core, and thus a varying magnetic field through the secondary winding.

A *rectifier* is an electrical device that converts alternating current (AC) to direct current (DC), a process known as rectification.

The *filter Capacitors* are generally connected to the output of the full wave bridge. These are used to transform the pulsating DC into pure DC.

4.3 Basics of IGBT

IGBT or Insulated Gate Bipolar Transistor is a device that combines the Metal Oxide Semiconductor Field Effect Transistor (MOSFET) gate driving characteristics with the high current and low saturation voltage of bipolar transistor. It acts as a high frequency, high current switch which is used in AC/DC Inverter, motor control and in switching mode power supplies applications.

It has lower VCE (Saturation) voltage which allows it to operate with a higher current density than with bipolar transistor. It can be modelled as a PNP transistor driven by a Power MOSFET. The normal gate driving voltage used is in the region of 15V where saturation voltage is obtained so that conduction losses are kept to a minimum.

The safe operating area is critical information that shows the maximum operating current and voltage of the device. It shows the forward bias SOA (safe operating area) and reverse bias SOA when the gate emitter junction is forward bias and reversed bias respectively.

The insulated gate bipolar transistor technology is improving with better switching speed, lower conduction voltage drop, higher current carrying capability and higher reliability. The availability of these devices with current up to 1kA, voltage ratings up to 2kV, switching speeds of 200ns and on state voltage down to 2.0V and below have made these devices a popular choice among designers in the world of power electronics.

The advancement of these technologies has enabled the inverter system solutions to be implemented for many consumer electronics appliances such as air conditioning controls and refrigerator controls.

4.3.1 IGBT Module

An indispensable device for the application of inverters to all industrial equipment, the IGBT (Insulated Gate Bipolar Transistor) module has driven the trend towards high currents and high voltage for the last 20 years since it was developed and produced. The module has evolved from the traditional flat planar chip structure towards the trench gate structure and, with the adoption of the CSTBT (Carrier Stored Trench-Gate Bipolar Transistor). The product line-up includes various types of IGBT modules, such as the NF series that has maintained its traditional shape and the NFH series for high-frequency switching.

Main Features

- Reduced power loss, enhanced short circuit capability and improved gate capacity.
- Built-in thermistor
- Thin packaging (17mm)
- Complies with the directive

Main Applications

General purpose inverters/AC servo/CVCF/solar power generation/wind power generation/CT/MRI/equipment for induction heating

Conventional IGBT modules, including those manufactured by SEMIKRON, are designed on the basis of a 3-mm-thick base plate, as shown in Figure 4.1. One or more substrates containing the IGBT chips, as well as the connection terminals are

then soldered on to this base plate. Aluminium wire bonds are used to connect the upper of the silicon chips to the substrate.

Figure 4.6: Basic Design of a conventional IGBT module. [14]

The main cause of failure in conventional IGBT modules is fatigue or cracking in the solder layers caused by temperature swing. Fatigue can lead to an increase in thermal resistance in the module, a process that is self-accelerating. Fatigue, for its part, occurs due to changes in thermally induced mechanical stress induced by extreme temperature swings; due to the different thermal expansion coefficients, these changes in mechanical stress arise when the firmly bonded materials heat up and cool down. The higher the value ΔT , the faster this process occurs. Conventional IGBT modules cannot meet the requirements.

One approach to solving this problem is to use materials with better adapted thermal properties. Base plates made of AlSiC, for instance, are often used in high performance power modules, as they have a far lower thermal expansion coefficient than copper alone. That said, AlSiC has a poorer thermal conductance and is very expensive, which is why it is not suitable for modules used in automotive applications.

Many years ago, SEMIKRON began looking at other ways of overcoming this problem. The result was SKiP technology (SEMIKRON integrated intelligent Power), modules with no base plate and an absolute minimum of soldered connections.

Figure 4.7: Design of an IGBT module based on SKiiP technology. [14]

In SKiiP modules, the substrate with the silicon chips is pressed onto the heat sink using a mechanical pressure contact system. As the substrate is not fixed to the heat sink, it can expand and contract under temperature change without resulting in the dreaded mechanical stress. The soldered chip connections are very small, and the thermal expansion coefficient of the DBC substrate is optimum for the semiconductor chips. Modules based on this type of technology therefore have a far higher thermal cycling resistance than conventional modules with a base plate.

4.3.2 SKiM 63 and SKiM 93

In order to create long-term reliable and ultra-compact modules, SKiiP technology was taken as a basis for further developments. This resulted in the development of the SKiM module family. SKiM 63 and SKiM 93 are the first two modules to use this new technology and are currently available as prototypes. These modules were developed especially for use in electric driven vehicles with challenging power density and ambient temperature requirements.

SKiM modules come in six-pack topology consisting of three independent half bridges in one case. Each of the three half-bridges is equipped with its own NTC temperature sensor. In keeping with current standards, the DC and AC main terminals are 17 mm high and are positioned on opposite sides of the module. The upper of the case contains the drive terminals. Here, too, the aim is to move away from soldered connections. For this reason, the driver board is connected using spring contacts with no soldering whatsoever.

The dimensions of the SKiM 63 and the SKiM 93 modules are 114 x 160 mm² and 150 x 160 mm², respectively.

Figure 4.8: SKiM, the first ever 100% solder free IGBT module Basic design of the IGBT module: sintered chips, no base plate, pressure contacted via springs. [14]

The power railing for the main terminals adjacent to and between the chips is pressed on to the DCB substrate without the use of soldered connections. This module design boasts a very low parasitic module inductance and resistance. The fact that the substrate is pressed on to the heat sink at many different points means that there is no bimetal effect. The substrate lies flat on the heat sink. At just 20 µm thick, the thermal paste layer is far thinner than in conventional modules with a base plate, where it is normally around 100 µm thick. This means that, despite the comparatively low thermal spreading, the same thermal properties are achieved. In future, chip soldering can be done away with entirely. Instead of soldering the chip to the substrate, the chip is attached in both SKiM modules using low-temperature sinter technology. In this type of connecting technology the connecting layer is made of silver. As silver has a very high melting point (960 °C), the typical fatigue effects that are found in soldered layers, melting point < 300 °C, do not occur.

For the module casing to meet the given thermal cycle capability requirements, the latest industrial materials have to be employed. For the SKiM modules SEMIKRON opted for a polyamide with a CTI (Comparative Tracking Index) > 600 and a RTI (Relative Temperature Index) of 150 °C.

Figure 4.9: The temperature cycling capability of SKiM is five times higher than standard modules. [14]

4.3.3 IGBT / diode chipset

In addition to choosing the optimum mechanical design, the ideal combination of IGBT and diode chip is also essential. For the envisaged applications, modules with 600 V and 1200 V off-state voltage are needed. Given the high temperature requirements, IGBT 3 chips from Infineon Technologies and CAL HD from SEMIKRON are used in the SKiM modules for 600 V applications, while for 1200 V applications the newly developed IGBT 4 chips and the recently developed CAL I4 [4], likewise from Infineon Technologies and Semikron, are used. These chips have a maximum permissible chip temperature of $T_{j,max} = 175\text{ }^{\circ}\text{C}$ and are thus able to meet the high temperature requirements, even in overload conditions. The technical data shown in Table 1 can be achieved with these chipsets. This data has been confirmed in initial circuit testing on the existing prototypes.

Table 1 SKiM electrical parameters

	SKiM 63	SKiM 93	
R_{thjs} IGBT	0,14	0,95	K/W
R_{thjs} Diode	0,27	0,18	K/W
I_C nom, 600V	600	900	A
I_C nom, 1200V	300	450	A
I_{RMS} , 600V ¹⁾	280	410	A
I_{RMS} , 1200V ²⁾	165	250	A

Conclusion

SKiM is a power semiconductor module that meets the highest of reliability requirements even under extreme ambient conditions. This is due to the consistent use of pressure and spring contact technology instead of solder technology, in combination with the latest industrial plastics. With the latest IGBT and diode technologies, high electrical power density can be achieved - in short, modules that are compact, highly efficient and reliable.

4.4 Series Transformer

An isolation transformer does not have a direct electrical path from the power input side to the power output side. The term is also used to define how much electrical isolation exists between the input and output windings. For example, when using line-voltage input transformers to power low voltage device handled by humans, a high degree of isolation is required for safety. Isolated transformers often use separate bobbins for the primary and secondary coil windings, but usually the windings are just wound on top of each other with insulation in between. There is usually an electrostatic shield between windings which is tied to transformer case. Non-Isolated transformers are becoming rare. A common example is the "Variac" which is a non-isolated variable transformer. Usually the term "auto-transformer" is used to describe non-isolated transformers.

They are rarely found in consumer products. Although any transformer with a separate primary and secondary winding is an isolation transformer to some extent, the term is usually used to denote a special-purpose transformer built just for that use. It is tested and rated to withstand a very high voltage difference, called the withstand voltage, so that even if thousands of volts are applied to the primary, it will not leak through to the protected side. These transformers are used in the medical industry, to protect patients hooked up to monitoring instruments that are powered by utility mains, as well as other uses. Without a transformer the live wire is live relative to ground. If you are at "ground" potential then touching the live wire makes you part of the return path.

With a transformer the output voltage is not referenced to ground - see diagram (a) below. There is no "return path" so you could (**stupidly**) safely touch the "live" conductor and ground and not received a shock.

This is because, if there is leakage or hard connection from the other side of the transformer to ground then there may still be a return path - as shown in (b) above. In the diagram the return path is shown as either capacitive or direct. If the coupling is capacitive then you may feel a "tickle" or somewhat mild "bite" from the live conductor. If the other conductor is grounded then you are back to the original transformer less situation. (Capacitive coupling may occur when an appliance body is connected to a conductor but there is no direct connection from body to ground. The body to ground proximity forms a capacitor.)

SO a transformer makes things **safer** by providing isolation relative to ground. The transformer has done its job. BUT with N items of equipment - if one has a fault from neutral to case or is wired wrongly this may defeat the transformer such that a second faulty device may then present a hazard to the user.

4.5 Protection Fuses (BLX-A)

A fuse is fault sensing and fault clearing device.

A fuse is a device that senses the fault and then clears the fault by blowing himself.

A fuse(s) or circuit breaker(s) is needed in any electrical system (AC or DC). These protection devices react to the amount of heat being produced by electricity passing through wires and/or components. They are used so as to protect wires and components from the extreme heat produced should there be an electrical overload or short circuit. When a short or overload occurs, the amps being drawn spike and this increases the heat produced in the wiring and components. When this occurs, a fuse or circuit breaker reacts almost instantly to stop the flow of electricity in the circuit and thereby stopping heat production. Without PROPERLY-SIZED FUSES OR CIRCUIT BREAKERS, this quick break in the circuit would not be possible, and damage to components and even FIRE could result. The wiring in your home or business is sized for specific amperage. Increasing the size of protection devices will cause your electrical system to not be protected adequately. Branch circuits feeding lights and 120-volt receptacles should have only a 15-amp or 20-amp protection devices, depending on the wire size. If you cannot locate the overload or short, keep the power to the circuit OFF and contact a qualified electrician.

3 Phase supply available in lab is applied to 3 phase HL-303 breakers

Features

- Triple Pole
- 415 Volts
- 63 Amperes Capacity

4.6 CT and PT

The Current Transformer (C.T.), is a type of “instrument transformer” that is designed to produce an alternating current in its secondary winding which is proportional to the current being measured in its primary.

Current transformers reduce high voltage currents to a much lower value and provide a convenient way of safely monitoring the actual electrical current flowing in an AC transmission line using a standard ammeter. The principal of operation of a current transformer is no different from that of an ordinary transformer.

A voltage transformer theory or potential transformer (P.T.) theory is just like a theory of general-purpose step-down transformer. Primary of this transformer is connected across the phase and ground. Just like the transformer used for stepping down purpose, potential transformer i.e. PT has lower turns winding at its secondary.

4.6.1 Current transformers

It can reduce or “step-down” current levels from thousands of amperes down to a standard output of a known ratio to either 5 Amps or 1 Amp for normal operation. Thus, small and accurate instruments and control devices can be used with CT’s because they are insulated away from any high-voltage power lines. There are a variety of metering applications and uses for current transformers such as with wattmeter’s, power factor meters, watt-hour meters, protective relays, or as trip coils in magnetic circuit breakers, or MCB’s. [16]

Figure 4.10: Current Transformer

4.6.2 Potential Transformer

Potential transformer or voltage transformer gets used in electrical power system for stepping down the system voltage to a safe value which can be fed to low ratings meters and relays. Commercially available relays and meters used for protection and metering, are designed for low voltage. This is a simplest form of potential transformer definition.

The system voltage is applied across the terminals of primary winding of that transformer, and then proportionate secondary voltage appears across the secondary terminals of the PT. The secondary voltage of the PT is generally 110 V

Figure 4.11: Potential Transformer

In an ideal potential transformer or voltage transformer, the ratio of primary and secondary voltages of transformer is equal to the turns ratio. [16]

HARDWARE AND SOFTWARE

5.1 Software and hardware simulation study

This chapter deals with the various circuits' simulation study and hardware. The results of the simulation are also included in the chapter. This chapter gives idea about the various circuit diagrams, their operating principles and finally the results of the simulation study.

5.2 Hardware fabrication and testing

In this section, the actual hardware fabrication of the Shunt IGBT and the real testing of the fabricated hardware are discussed. So, in order to simplify the discussion, the whole hardware prototype has been divided into three sections. The three sections are:

- Section I: Load parameter sensors and Reference Current Generator. This section is responsible to sense the actual current and voltage through the load and then generates the reference current that should be supplied by the Shunt IGBT so that the Shunt IGBT branch supplies only reactive component of the current while the source supplies the only active component of current
- Section II: Hysteresis Band generator and Shunt Inverter Hysteresis Band generator senses the actual current through the Shunt IGBT branch, compares the actual current with the reference current and then generates the gate signals to control the switching of the inverter. The gate signals are generated such that the actual current gets confined between the upper and the lower band of the reference current.
- Section III: Power Factor measurement unit.

Hence, section I and section II form the Shunt IGBT branch. The reactive power compensation of section III is done using section I and section II.

Circuits

This section includes the discussion of various hardware circuits actually used. The hardware design has been shown in the hardware description chapter. At first, using zero cross of load voltage and load current, the power factor angle is measured by microcontroller. The peak of the load current is also sensed using peak detector by microcontroller. This information gives the required lagging reactive component current to be provided by the Shunt IGBT branch. This current is the reference current for the hysteresis band controller. Hence, using digital circuits, the reference current is generated. The hysteresis band generator uses the Schmitt trigger. It takes input the actual and reference current, then generates the gate signal for inverter. The gate signal generated by hysteresis band controller is such that the actual current is made to be within the hysteresis band. The width of the hysteresis band can be changed just by changing the value of a potentiometer connected in the Schmitt trigger circuit. The respective hardware circuits are shown in the sub-topic below.

5.2.1 Section I: Current Sensing and Reference Current Generator

Figure 5.1: Sensing the load current and voltage

Figure shows the section I which is responsible for sensing the load current and voltage. It then generates the reference current that is to be supplied by the Shunt IGBT branch. This section has following components:

Current Probe and Voltage Probe: These probes are connected to CT and PT which sense the current and voltage across the load respectively. These probes are used to feed the voltage and current of the load to the section I.

- Offset circuit: The respective voltage signal of the current probe has DC offset. The offset circuit is used to cancel this DC offset in order to bring the signal to zero level for its zero cross and peak detection. It simply uses an Op-amp as unity inverting amplifier but with variable voltage in its non-inverting terminal using potentiometer. By varying the potentiometer, the signal can be given positive and negative dc offset.
- Voltage and Current Zero Cross Detector: It is an Op-Amp circuit that is responsible for generating the signal at the instant of zero cross of the voltage and current. The output of the ZCD is fed to the microcontroller in the form of interrupt.
- Peak Detector: It is a rectifier circuit with Op-Amp and capacitor whose output is equal to the peak value of the load current. The peak value is fed to the ADC pin of the microcontroller. The microcontroller finds the digital value of the analog current and measures the peak as digital value.
- Microcontroller: The microcontroller 16F877A measures real time current, the angular lap between the current and voltage. It then finally calculates the digital RMS value of the reference current magnitude and the phase angle of the reference current.

5.2.2 Section II: Hysteresis Band Generator and IGBT Driver

Figure 5.2: IGBT Driver

In hardware, the H-Bridge Invert is developed in bread board. The inverter consists of 2 pairs of MOSFETs. One pair of MOSFETs forms one leg of the inverter while the other pair form the other leg. Since, the voltage level of the microcontroller output and the gate signals required for MOSFETs switching is different, the driver ICs have been used. The gate signal from the hysteresis band controller controls the switching of MOSFETs. While switching the MOSFETs, there may be chance of the turning MOSFETs of the same leg ON simultaneously, causing a short circuit, which is undesired. In order to prevent this from happening, the gate signal to the higher MOSFET is the inverted signal to lower MOSFETs using a NOT gate. So that whenever one is ON the other is ensured to be always OFF and vice versa.

Here, DC battery has been used as the source, so the losses in the inverter during switching are compensated by the dc source itself. The inverter, in this project, is the source of the reactive power required for the load. The h-bridge inverter uses a coupling inductor in series with it, i.e. the Shunt IGBT is connected to load. The hysteresis band controller (or generator) is simply the Schmitt trigger with other necessary offset and amplifier circuits. The Schmitt trigger has two inputs: the actual current and the reference current.

5.2.2.1 Series and Shunt IGBT Module

Series and shunt IGBT modules are driven by MOSFETs to eliminate voltage and current problems such as harmonics, power factor correction, Voltage sag/swell etc.

Figure 5.3: IGBT modules

Each IGBT module contains two IGBTs and two modules are connected on each phase in series and shunt topology. An IGBT Driver circuit drives the IGBT modules during fault condition for specific duration. Each IGBT module internal connections are as follow: [19]

5.2.3 Section III: Automatic Power Factor Controller using Microcontroller

Power factor is basically defined as the ratio of the active power to reactive power or it is the phase difference between voltage and current. Active power performs useful work while Reactive power does no useful work but is used for developing the magnetic field required by the device. Most of the devices we use have power factor less than unity. Hence there is a requirement to bring this power factor close to unity. Here we are presenting a prototype for automatic power factor correction using PIC Microcontroller.

Figure 5.4: Power factor display

Circuit Diagram

5.3 Comparator Section

The 230 V, 50 Hz is step downed using voltage transformer and current transformer is used to extract the waveforms of current. The output of the voltage transformer is proportional to the voltage across the load and output of current transformer is

proportional to the current through the load. These waveforms are fed to Voltage Comparators constructed using LM358 op-amp. Since it is a zero-crossing detector, its output changes during zero crossing of the current and voltage waveforms. These outputs are fed to the PIC which does the further power factor calculations.

5.4 Microcontroller Section

PIC 16F877A microcontroller is the heart of this Automatic Power Factor Controller, it finds, displays and controls the Power Factor. To correct power factor, first we need to find the current power factor. It can be found by taking tangent of ratio of time between zero crossing of current and voltage waveforms and two successive zero crossing of voltage waveform. Then it displays the calculated power factor in the 16×2 LCD Display and switches ON the capacitors if required.

5.5 Correction Section

When load is connected the power supply, power factor is calculated by the PIC microcontroller. If the calculated power factor is less than 0.9 then the relay switches on the capacitor. The relays are switched using ULN2003 which is basically a driver IC. The current lead in capacitor compensates the corresponding current lag which is usually present in loads. Hence the phase difference between the current and voltage will be reduced.

Power Factor Correcting capacitor connected parallel to load through relay, if the relay is energized by microcontroller it will connect the capacitor parallel with load, if relay DE energized it will remove the capacitor from the load.

When the resistive load is on the power factor will be near to unity so the microcontroller doesn't energize the relay coil. When the inductive load is on the power factor decrease now the microcontroller energize the relay coil in order to compensate the excessive reactive power. Hence according to the load, the power factor is corrected. [21]

CONCLUSIONS AND FUTURE ASPECT

6.1 Conclusions

Voltage sags and current harmonics are the most important power quality problems in commercial and industrial utility's customers. These power quality problems can cause tripping of sensitive electronic equipment, abnormal operations of facilities and tremendous economic losses. Custom Power devices have now been of interest for more than a decade that are able to improve the reliability and the quality of power delivered to electric power customers. Unified Power Quality Conditioner consisting of two voltage source inverters with a common DC link is a Custom Power device and can simultaneously perform the tasks of Active Power Filter and Dynamic Voltage Restorer.

The power quality problems in distribution systems are not new but customer awareness of these problems increased recently. It is very difficult to maintain electric power quality at acceptable limits. One modern and very promising solution that deals with both load current and supply voltage imperfections is the Unified Power Quality Conditioner (UPQC). The performance of the UPQC is satisfactory in various power quality improvements, such as load balancing, neutral source current mitigation, power- factor correction, voltage harmonics mitigation, and current harmonic mitigation. Supply currents and load voltage harmonic levels are maintained below IEEE-519 standards under all conditions. The computational delay is reduced by indirectly controlling the three-phase supply currents/voltages. Moreover, the load and APF neutral currents are not sensed; hence, the number of current sensors is reduced. Therefore, with the help of these topologies can meet required load demand in future, increase the production in industries and increase the economy of the country.

A control scheme for power quality improvement in a three-phase four-wire distribution system has been proposed and investigated in a very close to realistic working conditions. The performance of the UPQC has been observed to be satisfactory for various power quality improvements like load balancing; source neutral current mitigation, power-factor correction, voltage and current harmonic mitigation, mitigation of voltage sag and swells. Further the performance of system under consideration was evaluated and found satisfactory under the case of voltage dip, demonstrating the strength of proposed scheme. It is observed that supply currents and load voltage harmonic levels are maintained below IEEE-519 standards. Moreover, the performance of UPQC has been found satisfactory during transient conditions. The rating and the number of VSI switches of UPQC can be further improved by integrating passive elements (i.e. star-delta transformer or other transformer configurations) for source neutral current mitigation. The experimental setup and the results are planned for future work. The instantaneous reactive power theory is used for shunt APF control algorithm by measuring mains voltage and currents. The conventional methods require measurements of the load, source and filter voltages and currents. The simulation results show that, when unbalanced and nonlinear load current or unbalanced and distorted mains voltage conditions, the control algorithms eliminate the impact of distortion and unbalance of load current on the power line, making the power factor unity. Meanwhile, the series APF isolates the loads voltages and source voltage, the shunt APF provides three-phase balanced and rated currents for the loads.

6.2 Future Aspects

Among above mentioned configurations, UPQC-DG could be the most interesting topology for a renewable-energy-based power system. This configuration can offer multifunctional options, namely, active power delivery from DG system to grid (normal DG operation), voltage and current-related power quality compensation (UPQC operation), and uninterruptible power supply operation. Commercial products have started to appear in the market to increase the renewable energy system connectivity by compensating some of the problem.

6.3 Future Work

The UPQC model as developed can be modified to be more effective in eliminating power quality related problems in power system. The various paths in which the presented work can be extended are listed below:

- A laboratory prototype can be made for the developed model.
- The model has been developed for right shunt UPQC configuration. The model can be modified for left shunt UPQC.
- Nowadays, generation of electricity from renewable sources has improved very much. Utilizing wind energy and solar energy as a renewable source to generate electricity has developed rapidly. UPQC can be combined with one or several distribution generation (DG) systems to provide good quality power to the consumers. Power generated by wind or solar energy can be fed to the DC link through converter to make the UPQC more effective during severe system conditions.

APPENDIX 1

PIC Controller-1 IGBT Control

```
#include <htc.h>
```

```
#include "delay.h"
```

```
#include "lcd.h"
```

```
_CONFIG(HS & BORDIS & PWRTE & WDTDIS & LVPDIS);
```

```
//Variable declaration
```

```
int new_Imag=0, new_angle=0, old_Imag=0, old_angle=0, Imag_sin_phi=0,  
theta=90;
```

```
int I_float_disp; //This variable is used to change the current value into  
// real value multiplied by 100. So, when displayed on lcd two digits after  
// decimal are preserved (Caution: it must contain only two digits after decimal)
```

```
char dummy, flag=0;
```

```
char x[91]={0,2,3,5,7,9,10,12,14,16,17,19,21,22,24,26,28,29,31,33,34,36,37,39,41,  
42,44,45,47,48,50,52,53,54,56,57,59,60,62,63,64,66,67,68,69,71,72,73,74,75,7  
7,78,79,80,81,82,83,84,85,86,87,87,88,89,90,91,91,92,93,93,94,95,95,96,96,97  
,97,97,98,98,98,99,99,99,99,100,100,100,100,100,100};
```

```
void adc_init()
```

```
{
```

```
PCFG3 = PCFG2 =0; PCFG1 = 1; //PORTAN0-AN4 USED as analog input
```

```
PCFG0 = 0;
```

```
CHS2 = CHS1 = 0; CHS0 = 1; //SELECTING CHANNEL AN1
```

```
ADCS2 = ADCS0 = 0; //32*TOSC,CLOCK SELECTED FOR min 1.6us,pic at  
20MHz
```

```
ADCS1 = 1; ADFM = 1;
```

```
}
```

```
void adc()
```

```
{
```

```
ADON = 1; delay_100us(2); ADGO=1; while(ADGO);
```

```
new_Imag = (int)((ADRESH << 8)+ADRESL);
```

```
new_Imag=new_Imag/8; // Brings Imag_new in the range of 127
```

```
}
```

```
void uart_init()
```

```
{
```

```
TXSTA = 0b10100100; RCSTA = 0b10010000; TRISC6 = 0;
```

```
TRISC7 = 1;
```

```
BRGH = 1; //high speed baud rate generator
```

```
SPBRG = 64; //BAUD RATE: 19.2kbps
```

```
SYNC = 0; //ASYNCHRONOUS MODE
```



```

SPEN = 1;      //SERIAL PORT ENABLE RX/TX TX9 = 0;      //8-bit transfer
mode
RX9 = 0;

TXIE=0;    //Disable transmit interrupt

RCIE = 1;    //ENABLE RECEIVE INTERRUPT

RCIF=0;      //no new data available initially
TXEN = 1;    //enable TX CREN = 1;      //enable RX

}

char sine(int angle)

{

if (angle>=0 && angle<=90)

return(x[angle]);

else if(angle>90&& angle<=180)

return(x[180-angle]);          //sin(180-x)=sin x else if(angle>180 &&
angle<=270)
return(-x[angle-180]);        //sin(x-180)=-sin x

else if (angle>270 && angle<=360)

return(-x[360-angle]);        //sin(360-x)=-sin x else
return 0;

}

```

```

void main()

{

//port configuration

TRISA=0xFF;      // For analog input TRISB=0b00000011;      //For interrupt
input  TRISC6=0;  TRISC7=1; //For  uart  communication  TRISD=0x00;
//For LCD
//Timer initialization and start

T1OSCEN=0; TMR1CS=0; TMR1ON=1;
//Interrupt enable

GIE = 1;  //RB0 interrupt

PEIE = 1; INTE = 1;
INTEDG = 1; //interrupt triggered by rising

INTF = 0; //when interrupt appears in RBO this flag is set uart_init();
adc_init(); LCD_init(); LCD_clear(); LCD_goto(1,4);
LCD_string("WELCOME!");

LCD_goto(2,1); LCD_string("STATCOM-PROJECT"); delay_nms(2000);
LCD_clear();

while(1)

{

//Read new_Imag adc();
//configure timer. These values might have been changed by delay function

T1CKPS1=0;

```

```

T1CKPS0=1; // for prescalar 1:2

T1OSCEN=0; TMR1CS=0; TMR1ON=1;

//Now we start to calculate angle flag=0;
while(!flag);//wait till interrupt (voltage zero cross) and
//reset timer if interrupt while(!RB1); //wait till zero cross of current
new_angle=TMR1H*256+TMR1L; new_angle=(int)(0.0072*new_angle);
//if new data available display on lcd and send it to 18f

if((new_Imag!=old_Imag)|| (new_angle!=old_angle))

{

//load new values to old old_Imag=new_Imag; old_angle=new_angle;

Imag_sin_phi=new_Imag*sine(new_angle); Imag_sin_phi=Imag_sin_phi/100;
I_float_disp=(int)(new_Imag*3.937); //127->5V, so x-
//>5/127*x (it is multiplied by 100 to reserve 2 digits
//after decimal
LCD_goto(1,1); LCD_string("Ip:");
LCD_float_value(I_float_disp);LCD_string("A"); LCD_goto(1,10);
LCD_string("PHI:");LCD_num(new_angle);
I_float_disp=(int)(Imag_sin_phi*3.937); //converting
//Isin(phi) to analog value with two decimal reserved
LCD_goto(2,1); LCD_string("Im:");
LCD_float_value(I_float_disp);LCD_string("A"); LCD_goto(2,10);
LCD_string("Ang:");LCD_num(theta);
//Sending char A 16f says new data is available

while(!TXIF); TXREG = 'A';
}

}

}

```

```

void interrupt isr(void)

{

//when interrupt in RB0. This means start timer to calculate phi if (INTF)
{

TMR1H=0x00;

TMR1L=0x00; //reset the timer when interrupt to 3000

INTF=0;

flag=1;

}

//when interrupt in RCIF. This means data has to be sent now. if(RCIF)
{

//Read Dummy dummy=RCREG;
//Transmit new_Imag while(!TXIF);

TXREG = (char)(Imag_sin_phi); //Imag_sin_phi

//Transmit new_angle while(!TXIF);
TXREG = (char)(theta);    //theta=90

RCIF=0;

}

}

```

APPENDIX 2

PIC Controller-2 Code (Power Factor)

```
//LCD Module Connections
sbit LCD_RS at RB4_bit;
sbit LCD_EN at RB5_bit;
sbit LCD_D4 at RB0_bit;
sbit LCD_D5 at RB1_bit;
sbit LCD_D6 at RB2_bit;
sbit LCD_D7 at RB3_bit;
sbit LCD_RS_Direction at TRISB4_bit;
sbit LCD_EN_Direction at TRISB5_bit;
sbit LCD_D4_Direction at TRISB0_bit;
sbit LCD_D5_Direction at TRISB1_bit;
sbit LCD_D6_Direction at TRISB2_bit;
sbit LCD_D7_Direction at TRISB3_bit; //End LCD Module Connections
int powerFactor()
{
    int a=0,b=0,t=0,x=0;
    float tm,pf;
    TMR1L=0;
    TMR1H=0;
    do
    {
        if(PORTA.F0 == 1)
            T1CON.F0 = 1;
        else if(PORTA.F0 == 0 && T1CON.F0 == 1)
        {
            T1CON.F0 = 0;
            break;
        }
    }while(1);
    a = (TMR1L | (TMR1H<<8)) * 2;
```

```

TMR1L=0;
TMR1H=0;
do
{
    if(PORTA.F0 == 1)
    {
        T1CON.F0=1;
        if(PORTA.F1==1)
        {
            T1CON.F0=0;
            break;
        }
    }
}while(1);

b = TMR1L | (TMR1H<<8);
tm = (float)b/a;
pf = cos(tm*2*3.14);
x=abs(ceil(pf*100));
return x;
}

void main()
{
    char c[]="0.00";
    int a,b,d,x,f,e;
    float tm,pf;
    Lcd_Init();
    Lcd_Cmd(_LCD_CURSOR_OFF); // Cursor off

    ADCON1 = 0x08; // To configure PORTA pins as digital
    TRISA.F0 = 1; // Makes First pin of PORTA as input
    TRISA.F1 = 1; //Makes Second pin of PORTA as input
    TRISD.F0 = 0; //Makes First pin of PORTD as output
    TRISD.F1 = 0; //Makes Second pin of PORTD as output

```

```

while(1)
{
    a = powerFactor();
    Delay_us(50);
    b = powerFactor();
    Delay_us(50);
    d = powerFactor();
    Delay_us(50);
    e = powerFactor();
    Delay_us(50);
    f = powerFactor();
    x = (a+b+d+f+e)/5;
    c[3]=x%10 + 0x30;
    x=x/10;
    c[2]=x%10 + 0x30;
    x=x/10;
    c[0]=x%10 + 0x30;

    Lcd_Out(1,1,"Power Factor");
    Lcd_Out(2,1,c);
    if(x<90)
    {
        PORTD.F0 = 1;
        PORTD.F0 = 1;
        Delay_ms(2000);
    }
    else
    {
        PORTD.F0 = 0;
        PORTD.F0 = 0;
    }
    Delay_ms(250);
}

```

List of Abbreviations

APF	Active Power Filter
DSTATCOM	Distribution Static Compensator
DVR	Dynamic Voltage Restorer
FACTS	Flexible AC Transmission System
IEEE	Institute of Electrical and Electronics Engineers
LPF	Low Pass Filter
PCC	Point of Common Coupling
PE	Power Electronics
PQ	Power Quality
PWM	Pulse Width Modulation
STS	State Transfer Switch
THD	Total Harmonic Distortion
UPQC	Unified Power Quality Conditioner
VSI	Voltage Source Inverter

List of Symbols

A	Ampere
C_{dc}	DC link capacitor
F	Farad
H	Harmonic Order
I_c	Capacitor Current
I_L	Load Current
I_s	Source Current
L_s	Source inductance
P_L	Load Active Power
P_s	Source Active Power
P_{SH}	Shunt Active Power
P_{SR}	Series Active Power
Q_L	Reactive power demand of load
Q_s	Reactive power supplied by source
Q_{Sh}	Reactive power handled by shunt inverter

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