APPENDIX 1

A1.1 POWER QUALITY PROBLEMS

It includes all possible situations in which the waveforms of the supply voltage or load current deviate from the sinusoidal waveform at rated frequency with amplitude corresponding to the rated RMS value for all three phases of a three-phase system. Power quality disturbance covers sudden, short duration deviation impulsive and oscillatory transients, voltage dips (or sags), short interruptions, as well as steady-state deviations, such as harmonics and flicker.

Voltage power quality problems:

- Voltage Sag
- Voltage Swell
- Voltage Interruption
- Under/ Over Voltage
- Voltage Flicker
- Harmonic Distortion
- Voltage Notching
- Transient Disturbance
- Outage and frequency variation
Voltage Sag

Voltage sag, as shown in Fig. A1.1, is a reduction in the RMS voltage in the range of 0.1 to 0.9 p.u. (retained) for duration greater than half a main cycle and less than 1 minute. It is often referred to as ‘sag’ and is caused by faults, increased load demand and transitional events such as large motor starting.

Figure A1.1 Voltage Sag

Voltage Swell

A voltage swell, as shown in Fig. A1.2, is an increase in the RMS voltage in the range of 1.1 to 1.8 p.u. for duration greater than half a main cycle and less than 1 minute. It is caused by system faults, load switching and capacitor switching.

Figure A1.2 Voltage Swell

Voltage Interruption

A voltage interruption, as shown in Fig. A1.3, is the complete loss of electric voltage. Interruptions can be of short duration (lasting less than 2 minutes) or long duration. A disconnection of electricity causes an
interruption—usually by the opening of a circuit breaker, line re-closer or fuse.

Figure A1.3 Voltage Interruption

Under/Over Voltage

Long-duration voltage variations that are outside the normal limits (that is, too high or too low) are most often caused by unusual conditions on the power system. For example, out-of-service lines or transformers sometimes cause under voltage, as shown in Fig. A1.4, conditions. These types of root-mean-square (RMS) voltage variations are normally short term, lasting less than one or two days. In addition, voltage can be reduced intentionally in response to a shortage of electric supply. Over voltage occurs when the nominal voltage rises above 110% for more than 1 minute.

Figure A1.4 Under voltage due to planned voltage reduction

Voltage Flicker

A waveform may exhibit voltage flicker, as shown in Fig. A1.5, if its waveform amplitude is modulated at frequencies less than 25 Hz, which
the human eye can detect as a variation in the lamp intensity of a standard bulb. Voltage flicker is caused by an arcing condition on the power system. Flicker problems can be corrected with the installation of filters, static VAR systems, or distribution static compensators.

**Figure A1.5 Voltage Flicker**

**Harmonic Distortion**

Harmonics are periodic sinusoidal distortions of the supply voltage or load current, as shown in Fig. A1.6, caused by non-linear loads. Harmonics are measured in integer multiples of the fundamental supply frequency. In commercial facilities, computers, lighting, and electronic office equipment generate harmonic distortion. In industrial facilities, adjustable-speed drives and other power electronic loads can generate significant amounts of harmonics. Solutions to problems caused by harmonic distortion include installing active or passive filters at the load or bus, or taking advantage of transformer connections that enable cancellation of zero-sequence components.

**Figure A1.6 Distorted Voltage Waveform**
Total Harmonic Distortion

The Total Harmonic Distortion block measures the total harmonic distortion (THD) of a periodic distorted signal. The signal can be a measured voltage or current. The THD is defined as the root mean square (RMS) value of the total harmonics of the signal, divided by the RMS value of its fundamental signal. The expression for voltage total harmonic distortion can be given as follows,

$$THD = \sqrt{\sum_{n=2,3,\ldots}^{\infty} \frac{E_{n \text{ rms}}^2}{E_{1 \text{ rms}}^2}}$$  \hspace{1cm} (A1.1)

The measurement is most commonly the ratio of the sum of the powers of all higher harmonic frequencies to the power at the first harmonic, or fundamental, frequency. It must be noted that when the value of Total Harmonic Distortion is low, the power quality will be better.

Voltage Notching

Voltage notching, as shown in FigureA1.7, is caused by the commutation of power electronic rectifiers. It is an effect that can raise PQ issues in any facility where solid-state rectifiers (for example, variable-speed drives) are used. When the drive DC link current is commutated from one rectifier thyristor to the next, an instant exists during which a line-to-line short circuit occurs at the input terminals to the rectifier. With this disturbance, any given phase voltage waveform will typically contain four notches per cycle as caused by a six-pulse electronic rectifier.
Transient Disturbances

Transient disturbances are undesirable momentary deviation of the supply voltage or load current and caused by the injection of energy by switching or by lightning. Transients are classified in two categories “Impulsive”, as shown in Fig. A1.8, and “oscillatory”, as shown in FigureA1.9.
Outage

Outage is defined as an interruption that has duration lasting in excess of one minute.

Frequency Deviation

It is a variation in frequency from the nominal supply frequency above/below a predetermined level, normally + 0.1%.

A1.2 SOURCES OF POWER QUALITY PROBLEMS

- Power electronic devices
- IT and office equipments
- Arching devices
- Load switching
- Large motor starting
- Embedded generation
- Sensitive equipment
- Storm and environment related damage

In this particular thesis, two problems related to power quality are focused on. They are voltage sag and harmonic distortion. In further chapters we shall see how voltage sag can be overcome using a Unified Power Flow Controller (UPFC). Total Harmonic Distortion for various electronic components will be measured and compared to establish the improvement in power quality with the addition of a UPFC to the power system.
APPENDIX 2

ATMEL 89C2051 MICROCONTROLLER DESCRIPTION

A2.1 FEATURES

- 2K Bytes of reprogrammable Flash Memory
- 2.7 V to 6V operating range
- Fully static operating : 0 Hz to 24 MHz
- Two level Program Memory Lock
- 128 x 8-Bit Internal RAM
- 15 Programmable I/O Lines
- Two 16-Bit Timer / Counters
- Six Interrupt Sources
- Programmable Serial UART Channel.
- Direct LED Drive outputs
- On-Chip Analog Comparator
- Low Power Idle and power down Modes

A 2.2 DESCRIPTION

The AT89C2051 is a low-voltage, high-performance CMOS 8-bit microcomputer with 2K bytes of Flash programmable and erasable read-only memory (PEROM). The device is manufactured using ATMEL high-density
nonvolatile memory technology and is compatible with the industry-standard MCS-51 instruction set. ATMEL AT89C2051 is a powerful microcomputer which provides a highly-flexible and cost-effective solution to many embedded control applications.

The AT89C2051 provides the following standard features: 2K bytes of Flash, 128 bytes of RAM, 15 I/O lines, two 16-bit timer/counters, a five vector two-level interrupt architecture, a full duplex serial port, a precision analog comparator, on-chip oscillator and clock circuitry. In addition, the AT89C2051 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port and interrupt system to continue functioning. The power-down mode saves the RAM contents but freezes the oscillator disabling all other chip functions until the next hardware resets.

A 2.3 PIN CONFIGURATION OF ATMEL 89C2051

![Pin Configuration Diagram]

Figure A2.1 Pin Configuration of ATMEL 89C2051 Microcontroller
A 2.4 BLOCK DIAGRAM

Figure A2.2 Block Diagram of Atmel 89C2051 Microcontroller

A 2.5 PIN DESCRIPTION

VCC-Supply voltage.

GND-Ground.
Port 1

Port 1 is a 8-bit bi-directional I/O port. Port pins P1.2 to P1.7 provide internal pull-ups. P1.0 and P1.1 require external pull-ups. P1.0 and P1.1 also serve as the positive input (AIN0) and the negative input (AIN1), respectively, of the on-chip precision analog comparator. Port 1 output buffers can sink 20 mA and can drive LED displays directly. When 1 is written to Port 1 pins, they can be used as inputs. When pins P1.2 to P1.7 are used as inputs. Port 1 also receives code data during Flash programming and verification.

Port 3

Pins P3.0 to P3.5 and P3.7 are seven bi-directional I/O pins with internal pull-ups. P3.6 is hard-wired as an input to the output of the on-chip comparator and is not accessible as a general purpose I/O pin. The Port 3 output buffers can sink 20 mA. When 1 is written to Port 3 pins they are pulled high by the internal pull-ups and can be used as inputs.

Port 3 also serves the functions of various special features of the AT89C2051 as listed below:

Table A 2.1 Special Features of ATMEL 89C2051 Microcontroller

<table>
<thead>
<tr>
<th>Port Pin</th>
<th>Alternate Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3.0</td>
<td>RXD (serial input port)</td>
</tr>
<tr>
<td>P3.1</td>
<td>TXD (serial output port)</td>
</tr>
<tr>
<td>P3.2</td>
<td>INT0 (external interrupt 0)</td>
</tr>
<tr>
<td>P3.3</td>
<td>INT1 (external interrupt 1)</td>
</tr>
<tr>
<td>P3.4</td>
<td>T0 (timer 0 external input)</td>
</tr>
<tr>
<td>P3.5</td>
<td>T1 (timer 1 external input)</td>
</tr>
</tbody>
</table>
Port 3 also receives some control signals for Flash programming and verification.

**RST**

Reset input. All I/O pins are reset to 1’s as soon as RST goes high. Holding the RST pin high for two machine cycles while the oscillator is running, resets the device. Each machine cycle takes 12 oscillator or clock cycles.

**XTAL1**

Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

**XTAL2**

Output from the inverting oscillator amplifier.

**A 2.6 OSCILLATOR CHARACTERISTICS**

The XTAL1 and XTAL2 are the input and output, respectively, of an inverting amplifier which can be configured for use as an on-chip oscillator. Either a quartz crystal or ceramic resonator may be used. To drive the device from an external clock source, XTAL2 should be left unconnected while XTAL1 is driven. There are no requirements on the duty cycle of the external clock signal, since the input to the internal clocking circuitry is through a divide-by-two flip-flop; but minimum and maximum voltage high and low time specifications must be observed.
A 2.7 OSCILLATOR CONNECTIONS

Figure A2.3 Oscillator Connections of ATMEL 89C2051 Microcontroller

Note: C1, C2 = 30 pF ± 10 pF for Crystals

= 40 pF ± 10 pF for Ceramic Resonators

A.2.3 PIC 16F84 DESCRIPTION

A2.3.1 Features

- CMOS Enhanced Flash / EEPROM Memory Technology
- Low power consumption and high speed technology
- Wide range operating voltage 2.0V to 5.5V operating range
- Maximum operating frequency : 20MHz
- Operating speed : DC - 20MHz clock input; DC ~ 200ns
Instruction cycle

- 68 bytes of data RAM
- 64 bytes of data EEPROM
- Program memory size 1K x 14
- Data memory size 68 x 8
- 10,000 erase / write cycles Enhanced FLASH memory program memory typical
- 10,000,000 typical erase / write cycles EEPROM data memory typical
- Packages : PDIP, SOIC, SSOP
- Power saving SLEEP mode
- Selectable oscillator options

A2.3.2 Description

The PIC 16F84A belongs to mid-range family of the PIC micro controller devices. There are also 13 I/O pins that are user-configured on a pin-to-pin basis. Some pins are multiplexed with other device functions. These functions include external interrupt, changes on PORTB interrupt and timer0 clock input. Table 5.1 details the pin out of the device with descriptions and details for each pin. There are two memory blocks in the PIC16F84A. These are the program memory and the data memory. Each block has its own bus, so that access to each block can occur during the same oscillator cycle. The data memory can further be broken down into the general purpose RAM and the Special Function Registers (SFRs). The SFRs used to control the peripheral modules. The data memory area also contains
the data EEPROM memory. This memory is not directly mapped into the data memory, but is indirectly mapped. That is, an indirect address pointer specifies the address of the data EEPROM memory to read/write. The 64 bytes of data EEPROM memory have the address range 0h-3Fh. is a low-voltage, high-performance CMOS 8-bit microcomputer with 2K bytes of Flash programmable and erasable read-only memory (PEROM). The device is manufactured using ATMEL high-density nonvolatile memory technology and is compatible with the industry-standard MCS-51 instruction set. By combining a versatile 8-bit CPU with flash on a monolithic chip, the ATMEL AT89C2051 is a powerful microcomputer which provides a highly-flexible and cost-effective solution to many embedded control applications.

A2.3.3 Pin Configuration of PIC 16F84

![Figure A 2.4 Pin Configuration of PIC 16F84 Microcontroller](image-url)
A2.3.4 Block Diagram

Figure A2.5 Block Diagram of PIC 16F84A Microcontroller
APPENDIX 3

PULSE GENERATION PROGRAM

A3.1 CODING FOR PULSE GENERATION

The pulse generation program using the 89C2051 ALP is as follows:

```
org 000h
Start :
mov p3,#09h
mov Tmod,#01h
mov T10,#0ffh
mov th0,#0a5h
setb tr0
again:
jnb tf0,again
clr tf0
clr tr0
mov p3,#06h
mov Tmod,#01h
mov T10,#0ffh
mov th0,#0a5h
setb tr0
again 1:
jnb tf0,again 1
clr tf0
```
clr tr0
mov p3,#0Ah
mov Tmod,#01h
mov t10,#0ffh
mov th0,#0a5h
setb tr0

again 2:
    jnb tf0,again 2
    clr tf0
    clr tr0
    mov p3,#05h
    mov Tmod,#01h
    mov t10,#0ffh
    mov th0,#0a5h
    setb tr0

again 3:
    jnb tf0,again 3
    clr tf0
    clr tr0
    sjmp start
APPENDIX 4

MOSFET IRF840

A4.1 INTRODUCTION

The MOSFET IRF840 is used in the experimental setup. The features, and pin configuration of IRF840 are given below.

A4.2 MOSFET – IRF 840 - FEATURES

- 28A, 100 V
- rDS (ON) = 0.0770
- Single Pulse Avalanche Energy Rated
- Nanosecond Switching Speeds
- Linear Transfer Characteristics
- High Input Impedance.

A4.3 PIN CONFIGURATION

Figure A4.1 Pin configuration of IRF840
APPENDIX 5

DIGITAL SIGNAL CONTROLLER

A5.1 INTRODUCTION

The digital signal controller employed in the hardware implementation is dsPIC30F2010. The features and the pin configuration are illustrated as given below.

A5.2 FEATURES

- 28 pin IC
- Operating Voltage : 2.5 to 5.5 V, \( V_{DD} = -0.3V \) to 5.5V
- Output current =3mA
- C compiler optimized instruction set architecture
- 83 base instructions with flexible addressing modes
- 24-bit wide instructions, 16-bit wide data path
- 12 Kbytes on-chip Flash program space
- 512 bytes on-chip data RAM
- 1 Kbyte on-volatile data EEPROM
- 16 x 16-bit working register array
A5.3 PIN CONFIGURATION OF DSPIC30F2010

Figure A5.1 Pin Configuration of dsPIC30F2010

Figure A5.2 Connection diagram
A supply of +5V is given to the dsPIC through the pins 13, 28 and 21 as in Figure A5.2. Crystal Oscillator of frequency 6 MHz is connected across the pins 9 and 18. The driving pulses for the gate of IGBTs are taken from the pins 23, 24, 25 and 26. These pins belong to the PWM channel of the dsPIC.

**Advantages of dsPIC over other controllers:**

- It has an in-built DSP engine
- 6 PWM output channel
- Complementary or Independent Output modes
- Edge and Centre-Aligned modes
- 4 duty cycle generators
- Dedicated time base with 4 modes
APPENDIX 6

DRIVER CIRCUIT

A6.1 DRIVER CIRCUIT

The main function of the driver circuit is to provide isolation between the high voltage circuit and the low voltage circuit and to provide drive the gate of IGBTs.

The driver circuit consists of the following components:

- IR2110- High and Low Side Driver
- Opto isolator
- IGBT – IHW2N120R2

Figure A6.1 Driver Circuit using IR2110
A6.2 **IR2110 - HIGH AND LOW SIDE DRIVER**

- \( V_{OFFSET} = 500 \text{ V}_{\text{max}} \)
- \( I_{o/+} = 2 \text{A} / 2 \text{A} \)
- \( V_{OUT} = 10 - 20 \text{ V} \)
- \( t_{on/off(\text{typ})} = 120 \text{ & 94 ns} \)
- Delay Matching = 10 ns max

**A6.2.1 Features**

- Floating channel designed for bootstrap operation fully operational upto +500V
- Tolerant to negative transient voltage
- \( dV/dt \) immune
- Gate drive supply range from 10 to 20V
- Under voltage lockout for both channels

![Pin Configuration of IR2110](image)

*Figure A6.2Pin Configuration of IR2110*

A supply of 5 V is connected to pin 9 i.e., \( V_{DD} \) as shown in FigureA6.2. The high and low inputs are given to the pins 10 and 12 respectively. The outputs are taken from the pins 1 and 7. These pins are connected to the gate of the IGBT.
A 6.3 OPTO ISOLATOR – PC 817

![Pin Configuration of PC817](image)

**Figure A6.3 Pin Configuration of PC817**

This consists of an LED combined with a phototransistor in the same package as shown in Fig. A6.3. It allows the transfer of signals from one circuit to another that cannot be connected electrically to the first because, for example, it works at a different voltage. Light (or infrared) from the LED falls on the phototransistor which is shielded from outside light. The insulation between the two is typically 2kV. Slotted opto-switches like the one shown are used for the detection of liquid levels and as event counters to indicate for instance, when the end of a tape has passed through the slot.

A6.3 IGBT -IHW25N120R2

A6.3.1 Specifications

- $V_{CE} = 1200V$
- $I_C = 25A$
- $V_{CE(sat)}$ at $T_j=25^\circ C = 1.6V$,
- $T_{j,\text{max}} = 175^\circ C$

A6.3.2 Features

- Powerful monolithic Body Diode with very low forward voltage
- Body diode clamps negative voltages
- High ruggedness, temperature stable behavior
- Low EMI