Harmonics in domestic power consumption engineering essay

The objectives of this project are to design a model in Matlab/Simulink of a Domestic power system. The model represents a domestic power source and load that contains both linear and non-linear devices. It will be a time-based model which means these devices will be switched ON and OFF at various timings. Means of monitoring the voltages and currents responses are also added to this model and they are discussed in the results discussion part of this report. Finally, harmonic filters are added to the power system and their influence in reducing the harmonics content is observed.

The approach taken for this project was to study the methods of simulation using Simulink and the examples related to Harmonics provided by this program. After that, a survey of Non-linear devices was conducted to observe the harmonics effects and to measure the values of the Total Harmonic Distortion (THD) and current amplitudes of the odd orders of the harmonics (i. e. 3rd, 5th, 7th harmonics and so on) of each device using a power quality meter. After completion of the survey, the measurements were added to the model and simulation of the power system is conducted.

The results showed….

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CHAPTER 1

INTRODUCTION

Background

Power system quality has become a major concern for both the power supplier and the end-user especially with the various aspects of power quality disturbance. The impact of harmonics on the modern power systems in specific has become a serious issue to the electrical power utilities and to the costumers as it may cause huge economic losses.

The impact of harmonic distortions on domestic power systems can be categorized to two categories: impact on the electrical power utilities of the power supplier and impact on the customer equipment and devices. From the power supplier's prospective, harmonic distortion may harm their major components like transformers, overhead transmission lines and cables. It might cause a reduction in the components' lifetime and hence cause economic losses to the power supplier due to maintenance and reinstallation. This, in turn, will increase the system losses and as a result will reduce the efficiency of the power plant.

From costumers' prospective (residential area or domestic load in this case), a distorted domestic power system will affect the equipment and the devices that are being used. Harmonic distortion may cause them to overheat and reduces their lifetime. As a result, an increase in the electricity bills and economic losses to the customer may occur.

The aim behind this project is to have a full understanding about non-linear domestic loads that exist in current residential power systems and their contribution to harmonic distortions. This project consists of a survey of measurements from a number of selected non-linear devices that may have an effect in the domestic power system in term of harmonics. After collecting these measurements, the distortion level will be compared to the international standards and a model will be designed in Simulink to represent the harmonics effect of these non-linear devices and then adding harmonic filters to mitigate their effect.

Problem Definition

The harmonics distortion produced by the non-linear devices in the domestic load can cause negative impacts on the domestic power system. Both the utilities and the customers are affected economically.

Objectives

Measuring and evaluating the harmonics that are produced by non-linear devices available in today's domestic loads than model them on Simulink. After that, further analysis and investigation for a solution to this harmonic distortion is to be done.

Scope and Limitations

This project will be focusing on the domestic loads that are connected to domestic power systems. It will only look into a specific power quality issue, which is harmonics and will disregard any other types of power quality disturbance. For this reason, the mitigation technique to reduce the total harmonic distortion will be considered is a passive harmonic filter.

Report organization

The final report consists of six chapters which are divided into sections and subsections for a better explanation of the contents of this report.

Chapter one discusses about the background of the project and explains briefly the impacts of the harmonics on the utilities and the customers and the relationship between harmonics and the economic losses. It also defines the problem, the objectives and the scope and limitations to this project.

Chapter two covers the literature review of research topic. It includes a proper definition of harmonics and lists their effects on power systems in terms of technical and economic losses. Moreover, the chapter gives information about harmonic sources and the available mitigation techniques that can be used to reduce the harmonics distortion.

Chapter three is about the practical and experimental work that has been done. It will discuss how the measurements and the evaluation of the harmonic distortion have been done and the equipment that were used. It will also include a subsection about the modelling part of the project and the blocks that were used in Simulink.

Chapter four will discuss the results acquired from the experimental work and briefly compare the harmonic distortion of the non-linear devices and the international standard.

Chapter five is about conclusion and implications of the project. It includes a final discussion, a conclusion and recommendation for further work or issues to be pursued.

CHAPTER 2

Literature Review

2. 1 Introduction

Power Quality disturbances can be defined as any power disturbance that will lead to voltage, current or frequency fluctuation that result in failure or misoperation of customer equipment. Power quality is considered to be a very important factor due to the fact that power is a part of our daily lives and any interruption or disturbance may cause into several problems such as data corruption, equipment damage, and data transmission errors and reduce equipment life. All these problems can result in huge economic losses to both the utility and the customers.

There are several types of power quality disturbances as listed below [4]:

Harmonics

Transients

Short-Duration Voltage Variations

Long-Duration Voltage Variations

Voltage Imbalance

Waveform Distortion

Voltage Fluctuation

Power Frequency Variations

This project will focus on one of the most important power quality disturbances which are harmonics. Harmonics are important to be analyzed as they occur in the industrial loads, residential loads and also in the utility. Analyzing harmonics will help to design a more stable system by applying the appropriate mitigation techniques that reduce harmonics.

2. 2 What is Harmonics?

A harmonic is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency 50-60 Hz. Total harmonic distortion is the contribution of all harmonic frequency currents to the fundamental [5].

http://referencedesigner. com/books/si/images/fouriertransform. png

2. 3 What is Inter-Harmonics?

Inter-harmonics are additional frequencies which are not an integer of the fundamental frequency that can be observed between the harmonics of the power frequency voltage and current. It appears as discrete frequencies or as a wide-band spectrum and can be found in power systems of all voltage classes [1]. There are different sources of inter-harmonic waveform distortion such as static frequency converters, cyclo-converters, induction motors, arching devices and power line carrier signals. The corresponding effects of these inter-harmonics are affecting power line carrier signalling and induce visual flicker in display devices such as cathode ray tubes (CRTs) [1].

2. 4 Harmonic Effects

Harmonics have many impacts on the electrical systems and equipment that it may cause overheating for some of the system components which will result in power losses that may decrease the life time of the components which means high economic losses for the utilities. Also if a consumer is having distorted waveforms, it will affect the life time of the equipment therefore again more losses for the consumer as well. Bottom line, harmonics impact is a chain reaction each problem will lead to many other problems [1].

Harmonics cause problems both on the supply system and within the insulation which can be summarized into the following [7]:

Overloading of Neutrals:

When the loads are not balanced, only the net out of balance current flows in the neutral. Installers (with the approval of the standards authorities) have taken advantage of this fact by installing half-sized neutral conductors. However, although the fundamental currents cancel out, the harmonic currents do not – in fact those that are an odd multiple of three times the fundamental, the ‘ triple-N’ harmonics, add in the neutral [8].

2. Effects on Transformers

Transformers are affected in two ways by harmonics. Firstly, the eddy current losses increase at full load with the square of the harmonic number. This results in a much higher operating temperature and a shorter life time.

Fortunately, few transformers are fully loaded; however the effect must be taken into account when selecting plant.

The second concern is the triple-N harmonics. When reflecting back to a delta winding they are all in phase, which leads the triple-N harmonics to get trapped and circulate in the delta winding and does not get absorbed onto the supply. However, the non-triple-N harmonics can pass through the delta connection winding. The circulating current has to be taken into account when rating the transformer [4].

3. Nuisance Tripping of Circuit Breakers

Residual current circuit breakers (RCCB) operate by summing the current in the phase and neutral conductors if the result is not within the rated limit, disconnecting the power from the load. Nuisance tripping can occur in the presence of harmonics for two reasons. Firstly, the RCCB device may not sum the higher frequency components correctly and therefore trips. Secondly, the kind of equipment that generates harmonics also generates switching noise that must be filtered at the equipment power connection. The filters normally used for this purpose have a capacitor from line and neutral to ground, which might lead into current leakage to ground [4].

4. Power Factor Correction Capacitors

Power-factor correction (PFC) capacitors are provided in order to draw a current with a leasing phase angle in order to compensate for the lagging current that is drawn by the inductive loads such as induction motors. The impedance of the PFC capacitor reduces as the frequency increases, while the source impedance is generally inductive and increases when the frequency increases. As a result, the capacitor is likely to carry high harmonic currents which may lead to it getting damaged, unless it has been specifically designed to with stand that high amount of current [4].

5. Skin Effect

The skin effect is said to happen when the alternating current tends to flow on the outer surface of a conductor. Skin effect is normally ignored as its effect is minor at power supply frequencies. However at above about 350Hz which occurs at the seventh harmonic and above, the skin effect will become significant and will be taken into consideration. As it will be causing additional losses and heating [4].

6. Induction Motors

Harmonics may affect the induction motors in a way that the harmonics may induce a flux to the rotor in an opposite direction to the rotor rotation which will reduce the motor efficiency also harmonics may increase the eddy current in the rotor which therefore will increase heat dissipation [9].

7. Zero-Crossing Noise

Many electronic controllers detect the point at which the supply voltage crosses zero volts to determine when loads should be turned on. This is done because switching inductive loads at zero voltage does not generate transients which may lead into reducing electromagnetic interference and stress on the semiconductor switching devices [9].

8. Harmonic Problems Affecting the Supply

When a harmonic current is drawn from the supply it gives rise to a harmonic voltage drop proportional to the source impedance at the point of common coupling (PCC) and the current. Since the supply network is generally inductive, the source impedance is higher at higher frequencies. Of course, the voltage at the PCC is already distorted by the harmonic currents drawn by other consumers and by the distortion inherent in transformers, and each consumer makes an additional contribution [9].

2. 5 Sources of Harmonics

Different non-linear loads produce different but identifiable harmonic spectra. This makes the task of recognizing the harmonics that are produced from those loads easier. Utilities and users of electric power have to become familiar with the signatures of different waveform distortions produced by specific harmonic sources.

This will help us figure out better mitigation methods in order to reduce the harmonics produces from the source. This will reduce the harmonics penetration to the electrical power system.

At the development of power electronic switching devices, harmonic current propagation was looked at from the perspective of design and operation of power apparatus devices with magnetic iron cores, like electric machines and transformers. At that time the main source of harmonics must have involved substation and customer transformers operating in the saturation region.

Harmonics are the by-products of modern electronics. They occur frequently when there are large numbers of personal computers (single phase loads), uninterruptible power supplies(UPSs), variable frequency drives (AC and DC) or any electronic device using solid state power switching supplies to convert incoming AC to DC. Non-linear loads create harmonics by drawing current in abrupt short pulses, rather than in a smooth sinusoidal manner [1].

All variable frequency drives cause harmonics because of the nature of the frontend rectifier design. The 6-pulse rectifier is the standard power circuit elementary configuration for most pulse width modulated variable frequency drives with Diode Bridge rectifiers sold in the marketplace today.

Harmonics are generated by non-linear loads, and can be divided into [1]:

- Saturable Devices

- Arcing Devices

- Power Electronics

2. 5. 1 Saturable Devices

Saturable devices are devices which operate under steady state conditions (constant voltage and current).

Examples of saturable devices are:

- Transformers

- Rotating Machines

2. 5. 2 Arcing Devices

Arcing devices are devices that consume high amount of current such as lighting ballasts, arc furnaces, welding machines and fluorescent lamps.

- lighting ballasts

Electronic lighting ballasts have become popular in recent years because of the overall improved efficiency. The light level can be maintained over an extended lifetime by feedback control of the running current and as result of changing the current it generates harmonics in the supply [1].

Small Uninterruptible Power Supplies (UPS)

For high power units, UPS is used. The aim is to make the power supply load look like a resistive load so that the input current appears sinusoidal and in phase with the applied voltage as a result of that UPS is a source of harmonics [1].

Compact Fluorescent Lamps (CFL)

The harmonic current spectrum is produced in CFL. These lamps are being widely used to replace filament bulbs in domestic properties and especially in hotels where serious harmonic problems are suddenly becoming common [1].

2. 5. 3 Power Electronics Devices

Switched mode power supplies (SMPS)

Majority of companies use modem electronic units like SMPS. The advantage to the equipment manufacturer is that the size, cost and weight is significantly reduced and the power unit can be made in almost any required form factor. But its disadvantage is that, rather than drawing continuous current from the supply, the power supply unit draws pulses of current which contain large amounts of third and higher harmonics and significant high frequency components [1].

Figure 2. 2 Switched Mode Power Supplies (DC-to-DC Converter)

6-Pulse Thyrister Rectifier

Variable speed controllers, UPS units and DC converters in general are usually based on the three-phase bridge. The six pulse bridge produces harmonics as 6n (- or +) 1. As we increase Pulse Bridge, harmonics will be less [11].

2. 6 Mitigation Techniques

There are many ways to reduce harmonics, ranging from variable frequency drive designs to the addition of auxiliary equipment. The primary methods used today to reduce harmonics are:

- 12-Pulse Converter

In this configuration, the front end of the bridge rectifier circuit uses twelve diodes instead of six. The advantages are the elimination of the 5th and 7th harmonics to a higher order where the 11th and 13th become the predominate harmonics. This will minimize the magnitude of harmonics, but will not eliminate them. The disadvantages are cost and construction, which also requires either a Delta-Delta and Delta-Wye transformer, “ Zig-Zag” transformer or an autotransformer to accomplish the 30° phase shifting necessary for proper operation. This configuration also affects the overall drive system efficiency rating because of the voltage drop associated with the transformer configuration requirement.

Transformers

Transformers have reactance and resistance which makes it represent the majority of the impedance found in lines feeding non-linear loads. Reactive impedance increases directly with frequency, naturally attenuating harmonics by reducing available current at higher frequencies. This technique is commonly used in reducing the current distortion of electric motor drives in industrial applications.

Delta-Delta connected transformers for some drives and Delta-Wye connected transformers for the remaining drives are used in order to trap the triple-n harmonics. This will lead into current distortion reduction [7].

Line Reactors

This method consists of connecting a line reactance in series with the harmonic source at which the reactance will reduce the harmonic current. However, the line reactance method has different advantages and disadvantages as shown in the Table 2. l[12].

Advantages

Disadvantages

Low Cost

Harmonics reduction is insignificant

Available in different values

Dynamic characteristics depend on the line capacity

Small power losses

At very low load conditions it may damage the line due to high harmonic currents

Table 2. 1 Advantages and disadvantages of Line Reactors

The amount of harmonic that can be reduced is a function of the impendence of the line reactor the higher the line impendence the higher the reduction in harmonics.

Active Filters

Active harmonic filters uses power electronic devices in order produce harmonic current components that cancel the harmonic current components that are produced by the nonlinear loads. The active harmonic filter is configured based on a pulse width modulated (PWM) voltage source inverter that interfaces to the system through a system interface filter. The active filter configuration that is shown in Figure 2. 6 is referred as a parallel active filter as the filter is connected in parallel with the nonlinear load that is compensated. Figure 2. 6 show the concept of the current cancelation so that the current being supplied from the source is sinusoidal. The voltage source inverter is used in the active filter in order to control the harmonics.

This inverter uses dc capacitors as the supply and can switch at high frequencies to generate a signal that can cancel the harmonics produced by the non-linear loads. The voltage distortion is reduced because the harmonic currents that flow through the source impedance are reduced [13].

http://ars. els-cdn. com/content/image/1-s2. 0-S0019057811001133-gr1. jpg

Passive Filters

Passive filters consist of capacitor, inductor and a resistor connected in parallel to a nonlinear load. Passive filters will provide a low impedance path for the harmonic current therefore will inject them to ground. Passive filters can be tuned to absorb one type of harmonic current or several types as shown in the Figure 2. 7 [14].

Figure 2. 7 Passive Tuned Filters: (a) Single Tuned (b) Double Tuned

Another important feature of the passive filters is that they can improve the power factor since they have a capacitance in their construction. Moreover, filters can be specified according to the connection type into two main groups, the series connection and parallel.

The filters power losses depends on the material used so the lower the losses the higher the cost of the filter so after all it’s a trade of between the power losses and the filter cost [15].

In conclusion, many techniques by which harmonics can be mitigated from the system but always there are some advantages and disadvantages for each technology which makes it appropriate for some applications and not for others. Moreover, the decision of using which mitigation technique depends mostly on the cost, reliability and power losses. Always important to keep in mind that theoretical calculation and assumptions for the type/size of mitigation technique does not always match with the practical findings due to some voltage disturbance and phase unbalancing.

2. 7 Harmonic Evaluation and Measurements

2. 7. 1 Introduction

Evaluating harmonic system is a very important step in the analysis and design process. In order to evaluate the harmonics sources we should follow some standards that are set by IEEE as they have specified some guidelines and limits that we should follow. Following those guidelines will be helpful during measurements and understanding the devices used.

2. 7. 2 Harmonics Limits

There are many standards which have been set by many organizations (national/international) in order to improve the quality of service provided and to protect the customers from all different effect of disturbances that may occurs in electrical systems. For this project we will discuss the limits specified by the Institute of Electrical and Electronics Engineers.

2. 7. 3 Institute of Electrical and Electronics Engineers (IEEE)

According to IEEE 519-1992 standards the total voltage distortion and the total current distortion limits should be within the specified limits as shown in Table 3. 1 and Table [2]:

Table 3. 1 Total Voltage Distortion Limits According to IEEE 519-1992

Table 2. 7 Total Current Distortion Limits According to IEEE 519-1992

SCR is the ratio of the maximum short circuit current to the maximum fundamental frequency load current at the point of common coupling (PCC) [].

2. 7. 4 Harmonics Evaluation

Harmonic currents produced by nonlinear loads can interact with the utility power supply. This interaction often gives a rise to voltage and current harmonic distortion observed in many places in the system. Therefore, to limit both voltage and current harmonic distortion, as seen in the limits set by the IEEE standard 519-1992 in order to limit the harmonic current injection from the end users to make the harmonic voltage levels on the overall power system acceptable [8].

The two most common used indices measuring the harmonic waveform are:

- Total Harmonic Distortion (THD)

- Total Demand Distortion (TDD)

Since there are two parties involved in limiting the total harmonic distortion which are divided between the utility and the customers, the evaluation is divided into two parts which are:

- Measurements of the currents that are being injected by the loads

- Calculations of the frequency response of the system impedance

The total harmonic distortion (THD) is a measure of the effective value of the harmonic components of a distorted waveform relative to the fundamental.

In order to calculate the total harmonic distortion for the voltage or current Equation (1) or (2) are used [1]:

(1) (2)

The total demand distortion (TDD) is expressed in terms of the maximum demand load current.

TDD can be calculated using Equation (3) [1]:

(3)

In computing the short circuit level at the point of common coupling the normal system condition that will result in minimum short circuit level will be taken into consideration as it causes the most severe impact to the system.

The short circuit current can be calculated using Equation (3. 3) [8]:

Where MVA and kV represent the three-phase short-circuit capacity in megavolt amperes and the line-to-line voltage at the point of common coupling in kV, respectively.

The load current should be evaluated in order to determine the short circuit ratio

Equation (3. 4) can be used to calculate the load current [8]:

3. 6 How to Evaluate Compliance

Harmonic currents produced by nonlinear loads can interact adversely with the utility supply system. The interaction often gives rise to voltage harmonic distortion and current harmonic distortion observed in many places in the power system. Therefore, it is required to identify the point of common coupling (PCC) in order to have a more accurate measurement and evaluation. For industrial and commercial end users, the

PCC is usually at the primary side of a service transformer that supplies the facility as shown in figures 3. 1 and 3. 2.