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Electrical Pollution: Maintaining Electric Service Quality.

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1. Electricity
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Abstract

Rapid innovations and discoveries in the field of electrical engineering are leading to an increased usage of electrical equipment. However, this proliferation of technology is also polluting the electrical power stream. Till now the electric industry has taken up the effort to curtail electrical pollution. However, with the de-regulation of the electric industry, the industry is rethinking their approach to curtailing electrical pollution. In this report, we shall look at the problems faced in curtailing electrical pollution due to proliferation of polluting equipment. We shall also look at the environmental pollution control effort and see, if any ideas could be used to curtail electrical pollution.

Contents

List of Tables

List of Figures

Chapter 1 Introduction

An Electric charge is a fundamental property of elementary particles such as electrons and protons. The phenomenon of electricity is associated with either moving or stationary electric charges. This is the basis for the science of electricity and for electrical technology too. In the last century, innovations in electrical technology have made it possible to generate electrical energy, transmit it over vast distances and utilize it to power a variety of equipment.

Since the beginning of this century, people have been finding an increasing number of uses for electricity. Today electrical energy powers a large amount of equipment that we use in our day to day lives. This electrical equipment helps us accomplish a wide-variety of tasks. Everyday electrical energy is used to power our telecommunication infrastructure, equipment in our factories, our transportation systems and even our house hold appliances. Electrical energy accounts for nearly 40% of all U.S energy requirements [1]. Electrical energy heavily influences out way of living. This has become increasingly evident in the last few decades, with the boom in the electrical and electronic industry.

1.1 The Electrical Ecosystem

Electricity is delivered through the electricity distribution system. The electrical distribution system is a vast and complex network of interconnected systems that help in delivering electricity to the end customer. This distribution system is the infrastructure that all electrical equipment relies on for proper functioning. Over the years, innovations in electrical technology have resulted in electrical equipment becoming more intelligent (emergence of digital electronics), more interconnected (emergence of communication) and more energy efficient (power electronics). The complexity of these systems is increasing by the day. At the same time, the increase in spending on digital electronics, adjustable speed drives, fuel cell devices and other power electronics by consumes is changing the electrical landscape.

The rapid rate of innovations in electrical technology is the primary force driving the proliferation of electrical technology. In the past few decades, innovation in electrical technology such semiconductors have lead to new breed of devices such as rectifiers, adjustable speed drives (ASD), microprocessors etc. In the last few decades, there has been increased consumer adaptation of electrical equipment, such as ASDs and computers. This increased proliferation of electrical technology is resulting in distribution networks taking on the appearance of an electrical ecosystem.

1.2 Electric Pollution

Most of these new devices possess non-linear load characteristics (An electrical characteristic), which is a cause of concern for electric utility companies. Electric utility companies and others in the electric industry are particularly concerned, over the effects of widespread consumer usage of equipment with non-linear load characteristics upon the quality of the electricity provided. One such side effect that non-linear loads have is injection of harmonic currents into electrical distribution lines. As we shall see later, the formation of harmonics within the power stream degrades power quality. Which in turn, affects the electricity distribution infrastructure and the numerous electrical devices connected to it. This is leading to a new form of pollution taking place, an electromagnetic pollution.

Electric utility companies own and control the electricity distribution infrastructure. Hence, they are responsible for the quality of the electricity that they deliver through their distribution system. Since electrical pollution affects the quality of electricity, they are particularly concerned about it. This is why electric utility companies have taken an early lead in the effort to curtail electrical pollution. However, the

utility companies cannot control the rapid the proliferation of the usage of electrical equipment that causes electrical pollution, specifically speaking electrical equipment with non-linear load characteristics. This makes detecting and stopping polluting devices a very expensive job. In addition to this, the deregulation of the electric industry is placing competitive pressures on electric companies. In the competitive drive to be more cost efficient, companies are becoming more reluctant to take on the additional financial burden of the electrical pollution control. If the current situation continues, it will result in further degradation in power quality.

However, at the same time society is becoming increasingly dependent upon electrical energy. As we have seen in the last few years with the boom in the electronic and computer industry. In a later chapter, we shall see in detail how future economic growth will be more heavily reliant upon new electrical technologies and the electrical infrastructure that will power. This makes electric pollution and the degradation of power quality that is associated with it a very concerning issue. Since, it affects the infrastructure that society depends upon every day.

In this report, we will look at how electrical pollution is similar to other forms of environmental pollution caused by technological proliferation, such as automobile emissions. We shall look at how curtailment efforts succeeded there and how similar measure can help in curtailing electrical pollution

Chapter 2 will provide a more technical description of the quality of electrical energy, what is electric pollution? We shall also look at the causes and effects of electrical pollution, and some of the technologies that can be used to curtail it. In Chapter 3, we shall look at the past regulation of the electric industry and the problems associated with curtailing electrical pollution, after the de-regulation. We will then look at the affects of that other forms technology proliferate have upon environmental pollution in Chapter 4. In Chapter5, we will see how government involvement succeeded in curtailing air pollution due to automobile emissions. In Chapter6, we shall go over the necessity for government involvement in the effort to curtail electrical pollution.

Chapter 2 Electric Pollution

2.1 Electric Service Quality

Electrical energy is an energy product just as fossil fuels, such as gasoline and coal. A customer that purchases electric energy can use it to power equipment such as motors, light bulbs, heaters, computers etc. However, unlike fossil fuels such as gasoline and coal, electric energy is not a natural resource, electricity is a man made resource. Electric energy is usually measured in terms of kilo Watt hours (kWh) [4].

A consumer buys electricity from an electric company, and he pays the company based on the amount energy he consumes. However, the supplying electricity to a customer is a service. The electric company provides the service of providing a continuous supply of electricity that can meet the energy requirements of the customer. Hence, Electric Service Quality dependence on two factors the availability of electrical energy and the quality of electrical energy. Availability of electricity depends on both the ability of the company to meet the customer's energy requirements (in term a range of quantity or load) and their ability to provide a supply of electricity without any disruptions (intentional and unintentional). The quality of electricity or sometimes referred to as "Power Quality" is dependent on characteristics such as continuity, voltage, frequency, and phase. So if the quality of electricity is high but the service is either prone to frequent disruptions, or is unable to meet the load demands of the customer, the quality of service degrades.

2.1.1 Quality of Electrical Energy

A consumer buys electricity. The quality of the electric energy they buy will affect the performance of the electrical/electronic equipment that they are using. The equipment manufactures expect the utility company to supply electricity whose characteristics meet certain standards. Hence, it is the responsibility of the utility company to see that the electricity sold meets the following requirements.

- The electric energy must be continuously available. The voltage supply must alternate at a constant frequency with a sinusoidal waveform and a constant magnitude. The magnitude of the voltage must be within the range recommended by the equipment manufacturer [5].

- In three phase systems, there must be perfect symmetry. The three voltages must be identical sinusoids shifted 120° in phase with each other [5].

The above condition is an ideal case. In real life there are bound to be some deviations from these ideal conditions. Bearing this in mind most equipment is designed to still function over small range of deviations. If you look at the specifications for any electrical/electronic equipment. You will notice that the manufacturer specifies the power range over which the equipment will work. However, any deviation greater than the specified operational range will cause the equipment to malfunction. This deviation is a degradation of the quality of electricity sold. This problem may cause the equipment to malfunction and thereby lead to an interruption in service. Hence it is also results in a degradation of the quality of electric service, since the quality of the service provide is inter-linked to the quality of the product sold. The quality of electrical energy is, also referred to as "power quality". You will see us using these terms interchangeably throughout this report. Power quality or quality of electrical energy can hence be defined as, "the degree to which both the utilization and delivery of electric power affect the performance of the electric equipment". In other words a degradation in power quality is, "Any power problem manifested in voltage, current, or frequency deviations that results in failure or improper operation of customer equipment" [6].

Any degradation in the quality of electricity due to loading equipment usually affects not only the consumer causing it but everyone who is supplied through the same feeder line or the same distribution company. Due to the affects of this disturbance, we can consider it to be a form of pollution. There are various types of disturbances that affect the consumer, such as harmonics, flicker, lightning strikes, faults and switching. However, harmonic currents are the most worrisome to distribution for electric utility companies. This is because harmonic currents are not easily noticeable unless there is constant monitoring.

2.2 History

John D. Gibbs and Lucien Gaulard patented the concept of an alternating current transmission system in 1881 [8]. George Westinghouse latter bought their patent. In 1891 the first commercial single-phase transmission system was installed by, Westinghouse at the Gold King Ore Mill, near Telluride Colorado [8]. This system consisted of two 100 Hp synchronous machines connect via a 3.6 km power line that operated at around 3000V, "one as a generator, the other as a motor, identical to assure identical wave forms" [8]. The twin machine setup was necessary in order to avoid problems caused by non-sinusoidal voltages. As early electricians noticed when using ac units in parallel ac and dc generators did not behave alike. In 1884, John Hopkinson found and explanation to this problem, he determined that "alternators submit to synchronization and stable parallel operation only when the output voltages have the same frequencies, same voltage polarity (phase sequence) and nearly identical waveforms". A parallel connection of two or more ac generators with equal RMS (root mean square) values but with different harmonic spectra, will cause circulation currents between the generators, this leading to armature overheating, mechanical oscillation and unstable operation" [8]. This is one of the very first power quality problems that electrical engineers faced.

Another early problem that engineer noticed was the development of voltages larger than the voltage measured at the generator's terminals, usually at a fundamental frequency of 125Hz. This problem was first reported in a document written by Steinmetz in 1893 and was referred to as the Framington River Line resonance [9]. The problem that occurred was noticed in a 10 km long power line that was supplied by a hydroelectric plant near Hartford Connecticut in 1890. According the Stienmetz "the line was plagued by an overvoltage". This was latter explained as, "a resonance condition near the 13^{th} Harmonic at 1600 Hz".

In the 19^{th} century, the French mathematician Jean Baptiste Fourier proved that any non-sinusoidal waveform that is periodic, (repeats over time) can be expressed as a sum of sinusoids. Each of the sinusoids that make up a periodic waveform are referred to as harmonics. This is because the frequency of each of these sinusoids is a multiple of the fundamental frequency of the original non-sinusoidal waveform. To understand this, consider a periodic wave with a fundamental/periodic frequency of ω. Then according Fourier:

$$f(x) = a_0 + \sum_{h=1}^{\infty} (a_h \cosh \omega t + b_h \sinh \omega t) \quad [7]$$

Today Fourier's theory is utilized to solve many problems in engineering and science, such as fluid mechanics, elasticity and electricity. Fourier's theory was used to explain a power quality problem for first time in 1894, by Edwin J. Houston and Arthur E. Kennelly [9]. In that year, they published a paper titled "The Harmonics of Alternating Current". In this paper, they used Fourier's Theory to explain a problem in electrical systems. In the foreword, the authors state "As much unnecessary mystery appears to surround the subject of harmonics in alternating currents, it may be of interest to point out the fact that the subject is in reality of great simplicity". In their paper they explain the concept of harmonics as " a superposition of such series of harmonics upon a plain sinusoidal fundamental wave will produce such a resultant [non-sinusoidal] wave" [4]. This was the first application of Fourier's theory to explain a power quality problem. As we shall

see in the next section harmonics in a power system are in even to this day is one of the most important issue in power quality.

2.3 Harmonics

One of the required characteristics of electricity is that the voltage supply must alternate at a constant frequency with a sinusoidal waveform and a constant magnitude. If this waveform is distorted it results in harmonic distortion occurs. As we have mentioned before, in an AC system the voltage and current must be sinusoidal, or else according to Fourier's Theory the original energy content will be dispersed over a range of harmonic frequencies. These

2.3.1 Measuring Harmonic Distortion

Harmonics currents in power distribution network are a major problem in distribution lines. They cannot be totally eliminated, however they and can be minimized. As we shall be seeing shortly this can be done by using various mitigation methods. In order to do all this we must first understand how we can quantify harmonic distortion. The distortion in a periodic sinusoidal current wave is measured in terms of "Total Harmonic Distortion (THD_I)" [10].

$$THD_I = \frac{\sqrt{\sum_{h\neq 1} I_h^2}}{I} \qquad THD_v = \frac{\sqrt{\sum_{h\neq 1} V_h^2}}{V}$$

That is the total harmonic distortion of the current wave is equal to the square root of the sum of each harmonic current component raised to the power two over the original current. Now having found a way to quantify and measure harmonic distortion the next step is to decide upon a threshold value. Normally if the THD_I is < 10 % it is supposed to be mildly distorted [10]. Similarly, THD_V is maintained to be < 5%.

2.4 Causes of Power Pollution

Based on some national and local surveys 69% of disturbances are caused on the customer side and around 31% are on the utility side. On the customer-side, these disturbances are caused by a variety of reasons such as ground surge protection (28%), faulty equipment (28%), sages and swells in voltage (24%), harmonics (17%) and surges (4%) [11]. Disturbances/distortion to the waveform of the supplied electricity that are induced by loading equipment of the are in essence a form of electrical polluting. Since, this distortion results in harmonics, sags and swells in the power stream.

2.4.1 Causes of Harmonic Pollution

Harmonics in the power distribution network are mostly caused by electrical equipment that, have non-linear voltage and current characteristics. These types of equipment are referred to as non-linear loads. Most non-linear loads fall under three categories.

1. **Rectifiers:** These are circuits that convert AC into DC. They can be found in many common appliances like PCs, televisions, battery chargers and also ASDs, electroplating systems and electronic ballasts [12].

2. **Ferromagnetic Equipment:** Any equipment that uses a magnetic core falls under this category. For example transformers and inductors with magnetic core [12].

3. **Electric Arc Devices:** This category include all equipment that generate electric arcs, such as Arc Furnaces, Arc welders and Fluorescent lamps [12].

2.4.2 Causes of Momentary disturbances:

Momentary disturbances such as sags and swell in voltages account for 55% of disturbances on the utility side [11]. These type of disturbances result in momentary variation in the supplied voltages hence creating sags and in swells. These are the causes for most of these disturbances

1. **Lightning:** Lightning is an electrostatic discharge phenomenon that occurs in the atmosphere. Similar to the electrostatic discharge that happens when you touch a metallic object after you have walked over a carpet. Lightning tends to strike the tallest object in a given area since it is the least path of resistance to the ground. In cities with large building this is usually large buildings. However out in the country side electric distribution line tend to tallest object around. Hence being the target of lightning strikes. [13]

2. **Faults:** Faults are usually caused by short circuits triggered by lightning strikes, broken limbs animals toughing energized terminals while also touching other terminals or ground. [13]

3. **Switching:** Switching faults are mostly caused momentary surges in demand when large electrical devices such as motors are switched on. [13]

2.5 Effects of Electricity Pollution

According to a 1991 Business Week estimate electrical power pollution was at that time costing U.S. businesses around $26 billion a year [14]. The flow of harmonic currents inside a power distribution network is a major causes of degradation in power quality. In most network topologies, the utility company uses a single feeder line to supply multiple customers. If any particular customer is causing harmonic pollution in the line. It usually is very difficult to identify due to the shared nature of the supply. Hence, harmonic pollution is a major concern for utility companies since it is hard to identify the exact cause. "The harmonic pollution is easy to identify, sometimes hard to analyze but still harder to predict. Since nonlinear equipment, the source of harmonics, is virtually industry's only replacement option, and since harmonics can't be eliminated unless nonlinear loads are avoided, all industry is increasingly exposed." [15]

2.5.1 Effects of Harmonic Pollution:

Given below are some of the various ways that electrical equipment are affected by harmonic pollution [16].

- **Resonance:** Resonance occurs when a non-linear that has a specific characteristic impedance. At resonance the current passing through the equipment is much larger then the expected value. For a power network the usual range in which resonance occurs is between 140 and 800 Hz [16]. These excessive harmonic currents due to resonance result in damage to equipment on both the consumer and the utility side.

- **Fuse Blowing in Capacitor banks:** Capacitor banks usually are protected from excessive currents by a fuse. These fuses are prone to blowing due to harmonic currents from the capacitor bank. This ends up being a nuisance to the consumer.

- **Overheating of transformers:** The current density inside a conductor is dependent on the frequency of the current. The higher the frequency the higher the current density at the surface. This phenomenon

called "Skin Effect". The Harmonic currents in the transformer encounter higher resistance s than the 60 Hz current. This leads to excessive losses due to overheating in the transformer. This affects both utility companies and consumers.

- **Power loss in motor loads:** This is similar to the "skin effect" problem that transformers face when there are harmonic currents. The loss in motors is more observable, since it affects the mechanical output of the motor. This problem affects motors on the utility side.

- **Malfunction of digital timers:** Digital timers are found in computer and nearly any other electronic equipment that use digital circuits. These circuits use the 60 Hz voltage signal form the power to generate a clock pulse. This clock pulses provide the timing operation for equipment and, hence is essential for its proper operation. Harmonic currents degrade the clock pulse and cause the equipment to malfunction. This is probably the most disturbing effect of Harmonic currents, since electronic such as computers make up a large portion of the electrical. For instance, it is estimated that 43% of affected devices are computers and microprocessor [16]. It is also interesting to note that most electronic devices use rectifiers which are a major cause for harmonic currents in power distribution lines.

- **Excessive neutral currents:** Current is supposed to flow in the neutral conductor only when a system is unbalanced and not when it is balanced. However, when non-linear loads are use it has been noticed that excessively large neutral currents flow. As a matter of fact in the 1980 when personal computer started to proliferate electric fires in office buildings were trace to overload neutral conductors. This is also affects the consumer.

- **Measurement errors:** Harmonic currents are known to speed up or slow down electric meters. This leads to revenue losses for utility companies.

- **Inaccuracy in electronic timers:** Harmonics in the power stream may cause certain types of control systems to malfunction due to jitter in the triggering of the solid-switches.

- **Interference with Telephone communication:** When telephone lines are in proximity to feeder lines. The harmonic currents in the feeder line will lead to electromagnetic interference with telephone line. This leads to disruption or degradation in communication.

2.5.2 Distribution network Topologies:

The North American electrical power system is one of the largest and most complex machines of this age. It consists of power generation plants, transmission networks and local distribution networks. The power grid forms the backbone of electrical power system. It consists of interconnected transmission lines between the various distributors and power generation plants. The complex interconnect-network that makes up the power grids consists of the 670,000 miles of 22kV electric lines in all [17].

The many companies that own the various transmission lines and power plants work together in monitoring the state of the power grid. In order to facilitate this The North American Electric Reliability Council (NERC), after a blackout in 1965 that left almost 30 million people in the northeastern United States and southeastern Ontario, Canada without electricity [17]. NERC is a nonprofit corporation owned by ten regional councils WSCC (Western Systems Coordinating Council), NPCC (Northeast Power Coordinating Council), MACC (Mid Atlantic Coordinating Council), SERC (Southeastern Electric Reliability Council), FRCC (Florida Reliability Coordinating Council), MAPP (Mid-Continent Area Power Pool), SPP (Southwest Power Pool), ECAR (East Central Area Reliability Coordinating Agreement), ERCOT (Electric Reliability Council of Texas), MAIN (Mid-America Interconnect Network) [18]. The members of the

regional councils account for virtually all the electricity supplied in the United States, Canada, and a part of Mexico. The North American power grid is divided into four regions Eastern Interconnect, Western Interconnect, Texas Interconnect and Quebec Interconnect.

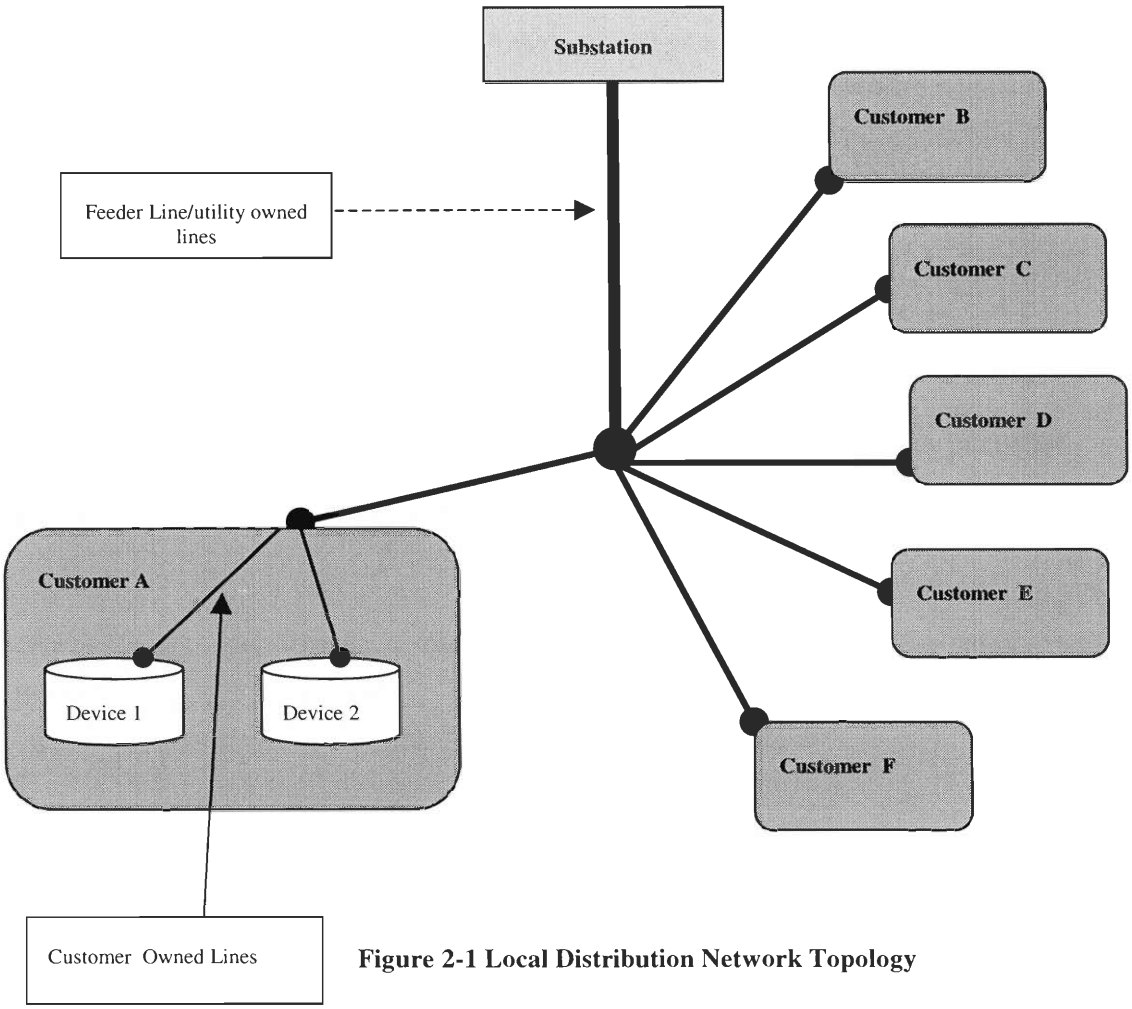

Figure 2-1 Local Distribution Network Topology

Transmission lines end at substations where the high voltage of transmission is then stepped down to the primary distribution voltage level. The low-voltage power is than supplied to the end customer over a local distribution network. Figure 2-1 shows a simplified block diagram of what a typical local distribution network would like. Usually multiple customers are served by a single feeder line with no electrical isolation between customers. However based on energy requirements utility companies do provide separate feeder line to large installations such office buildings and factories utility companies.

When certain customers say customer A's operates electrical equipment that cause harmonic currents in the line these currents will show up every where else hence affecting customer B, C, D, E, and F (refer fig. 2-2). However, each customer that is supplied owns has there own house wiring. So not only are the devices of the polluter affected, but so are all the other devices. This is a major concern for utility companies. Since the utility company does not own or operate the device that is causing harmonic pollution they cannot predict where harmonic pollution will occur. It would also be too expensive to either setup filters on each line, or electrically isolate all customers. Even in the case of large customers might be provided through a separate feeder line harmonics can be problematic. If the customer has a large internal network, such as a university or an office building, when harmonics will affect all the equipment on the network. In such a case the

customer would have to spend a significant amount of money in detecting the polluting device and preventing further pollution.

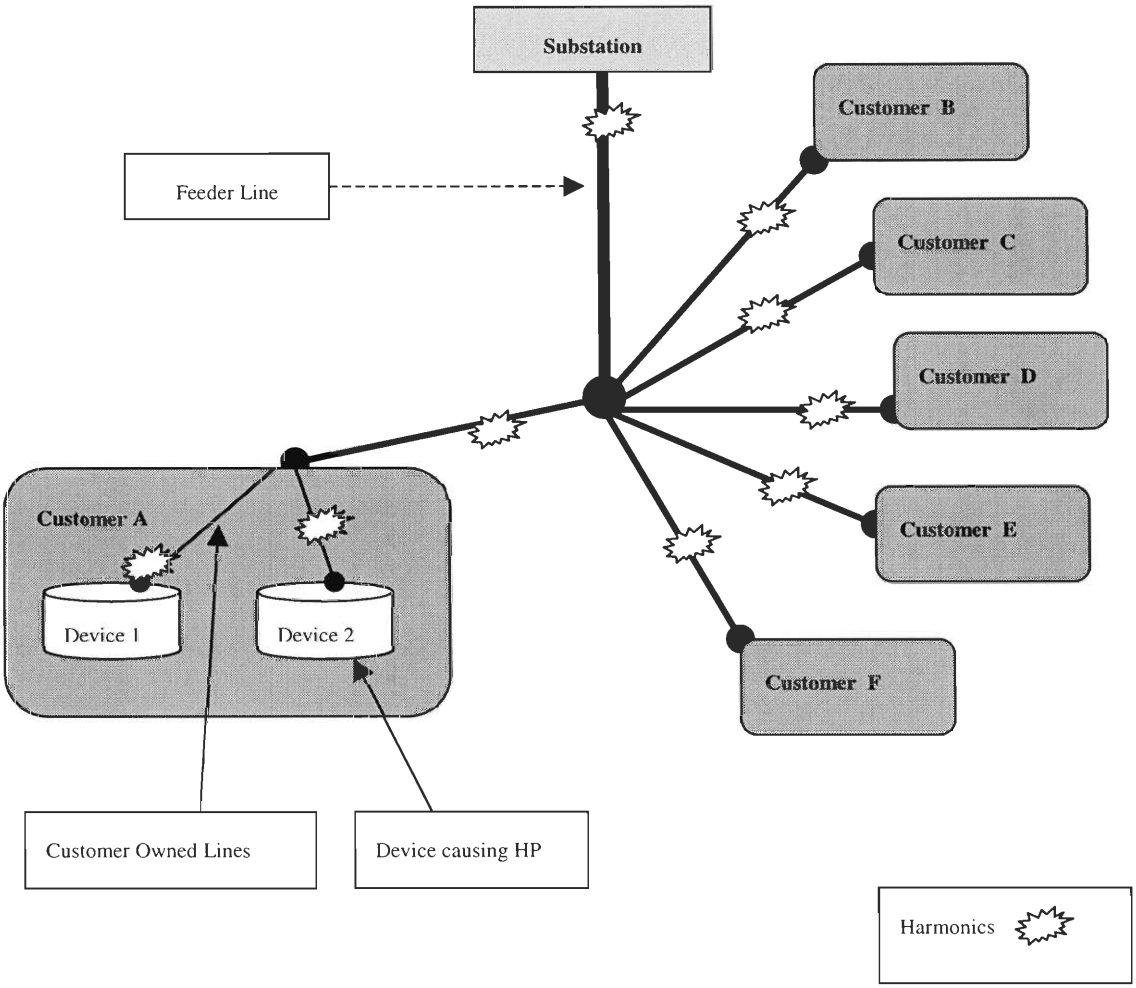

Figure 2-2 Effects of Harmonics in a Local Distribution Network

2.6 Mitigation Techniques

Disturbances in the electrical ecosystem are very different depending on where they originate. We can now classify most disturbances and problems in electric service quality into two categories based on their origination.

1. Distribution equipment affecting the system (Utility fault.)

2. Loading equipment affecting the system (Customer fault.)

2.6.1 Utility side:

- **Network topology, load distribution:** Distribution line owners should make it a point to layout network topologies, so that customers with frequent disturbances are isolated from the rest with dedicate feeders, where ever this is economically justifiable.

- **Lightning Arrest0rs and Proper tree trimming:** Nature seems to be the cause of most utility side disturbances. An estimated 61% of utility side disturbances are due to either surges, sages or swells in the voltages [11]. However it is the duty of the utility company to minimize the disturbance to what ever extent they can. This means using lightning arrestors on electric power poles and trimming trees in the proximity to electric power lines.

- **Strategically located harmonic filters and power conditioners:** View "Harmonic Current Filters" in the following section.

2.6.2 Consumer side:

- **Reduce noise:** Usage of oversize neutral conductors to 150-200% of phase-conductor current ratings. Usage of isolation transformers close to the load. Derate transformers, generators and motors. Use true RMS sensing meters, relays and circuit breaker trip units [21]. Confirm all controls, particularly those used for generator speed and paralleling, will operate properly with nonlinear loads. Select power sources with low output impedance to minimize voltage distortion. Provide line filters to remove the harmonic loads from the source.

- **Adjustable Speed Drives (ASDs):** Equipping ASDs with line reactance help reducing affects of voltage surges on them.

- **Voltage Regulators:** Voltage regulators such as ferro-resonant regulators can act as power conditioners hence slowing variations of voltage such as sags and swells. So can fast-acting voltage regulators.

- **Uninterruptible Power Supplies:**

- **Static Var Compensators (SVCs):** Static Var Compensators can be used to successfully mitigate flicker.

- **Harmonic Current Filters:** When harmonic currents form into a distribution system, they permeate it. The biggest problem with harmonics currents is that they affect every device on the network. Devices like microprocessors being the most sensitive to it. In essence, harmonic currents pollute the electrical ecosystem, and hence should be viewed as a pollution problem. Harmonic currents can not be totally eliminated from the power stream. However, the THD_v and THD_I levels can be minimized to more tolerable levels. By using special filters such as "shunt passive filters" to prevent harmonic currents from being injected into a network THD_v and THD_i levels can be reduced. Shunt filters have the advantage of being simple and rugged. However, when it comes to larger loads the usage of multiple filters is recommended. Passive filters such as shunt filters also have some drawbacks. New techniques are being used to design better active and hybrid filters.

  Filters essentially isolate harmonic pollution from permeating to the rest of the network. Hence, the location of the filter will dictate how effective it is. Utility companies that own distribution lines can setup filters at critical points in their network. This would prevent pollution from one customer (customer A) from effective others in his neighborhood (customer B). This solution is effective only to

a degree. Since harmonic/electric pollution, such as harmonic currents can be injected into a network from anywhere, by any customer, it will be cost prohibitive to setup filters every where. Also utility side filters cannot help reduce harmonic/electric pollution inside a electricity lines that are owned by the customer (Electrical wiring inside and Office Building). A more effective way of solving this is to install the filter on the device it self. So that the device cannot inject harmonic current pollution into any network.

2.7 Harmonic mitigation Standards

Till now we have looked at what Harmonic pollution is, what causeses it, how it affects us , and how it is measured. We will now look at the various standards used to curtail harmonic pollution. It must be understood that it is not necessary of totally elminate Harmonic pollution, but it is necessary reduce it to tolerable values. Inorder to do so we need to know what tolerable levels of Harmonic Pollution are needed.

There are two major standards used in limiting harmonics the American standard and the European standard. The American recommendation is based upon the IEEE Standard 519-1992 [19]. This standard recommendes limitations for both volatage and current distrotions. These recommended values for Total demand distortion (TDD) range between 5 to 20 dependeding upon the current load levels. The European standard EN 50160 is based on the probablistic nature of harmonics and are hence not the same as the American standards [19]. The American standard is also much more stringent then the Eurpoean standards. These limits are aimed at maximum harmonic pollutions that the consumer can produce, and hence should be used by electrical equipment manufacurers.

Chapter 3 Power Regulation

Till this point we have seen how it harmonic pollution affects both consumers and suppliers. We have also looked at the various technologies that can be used to help curtail it. There is a great deal of awareness and concern in the electric power industry about harmonic pollution, but despite this up till now the industry has been fighting a losing battle against harmonic pollution. Part of this problem can be attributed to the fact that there are now laws that deal with the problem of power pollution. At the same time, the government is embarking on an effort to de-regulate the previously regulated electric industry. In a bid to make the market place more competitive. In this chapter, we shall look in detail at the various legal problems faced by the industry in curtailing Harmonic Pollution.

3.1 The Electric Power Business before Deregulation

As we have said before Electric Energy is a product. Electric companies produce Electric Energy and sell it to the consumer. Since Electricity is considered to be a product, the relationship between an electricity producer and consumer is governed by the rules of trade. These laws play an important role in determining the extent to which power company can prevent HP. The Government both at the state and federal levels have regulatory bodies that regulate power trade (whether is producer-producer or producer-consumer). One of the biggest legal issues that power companies face is the legal rights that they and the customers have. These rights which are defined by current laws are unclear in respect to harmonic pollution. One of the issues that we shall look into latter is, the need the government to help with curtailing harmonic pollution. However, before we get to that we should understand how the power trade business works and how its is regulated.

If we were to look at the electric power system as a whole, we will see that it is highly complex. The power systems consists of power plants where electricity is generated which then is transmitted to consumers through distribution lines. In the beginning when power systems were simple. The power plants that supplied power to a consumers were nearby. As demand increased over the years the need to construct larger plants arose, as a result the generation capacity of the plants increased. Since transporting fuel (coal, oil, gas) is more expensive then transporting electricity and in some case impossible (hydro-electric), power plants were being build farther from the consumer.

At the same time, the number of consumers grew which lead the electric utilities to build larger distribution networks. This lead to the large and complex nature of the electric power supply system. In a majority of cases the utility companies that owned the power plants also owned the distribution nets. Despite this there were still many small independent power plants, but in the 1950s and 60s the industry went through a period of consolidation. In most case regional companies consolidated in order to make it more cost effective to build fewer but larger power generation plants and reduce duplication of distribution nets. These are some of the reasons to, why electric companies operate on a regional basis?

So why did governments at both state and federal level allow the formation of monopolies, and then set about regulating them? Vernon Smith's article "Regulatory Reform in the Electric Power Industry" in the quarterly magazine "Regulation" provides a very good explanation of why these monopolies were allowed to form [20]. According to Smith, the reasoning behind this was primarily economic in nature. The electric power industry along with others industries such as telephone, water and natural gas, were viewed by economists to be inherent "natural monopolies". In other words, the economies of scales would lead to the

emergence of only one company and hence monopolistic prices would prevail [22]. Smith points out two arguments that economists of the past have taken:

1. There are economies of scale involved in the production and delivery of electricity.

2. Duplication of facilities is inefficient.

The first reason is raised as a benefit for both the consumer and the utility companies, it means that a single firm can server the market at a lower cost than multiple competitors, because of lower operating overhead. The second reason leads us to believe that duplication of systems leads to inefficiency and hence higher costs. Both of these views have hence since been challenged, especially since the successful break up of the telephone industry, which lead to a tremendous competition, and hence the consumer benefits that we see in that industry today.

3.1.1 State Level Regulation before the start of deregulation

Power utility companies enjoy the status of being exclusive franchises for power production and distribution. At the same time society of the last 50 years has become ever more dependent upon electric energy. Due to unique monopolistic privilege of electric utilities, they are required by the law to take upon special responsibilities and duties. These duties vary from state to state and are defined by the public utility laws of the state in which they operate. For instance in Massachusetts the "Department of Telecommunication and Energy" (formerly Department of public utilities) is in charge of regulating electric utilities in the state of Massachusetts. The following excerpt taken from the web site of the Massachusetts "Department of Telecommunication and Energy" gives us an idea of the statute that they abide by.

> "The mission of the Department is to ensure that utility consumers are provided with the most reliable service at the lowest possible cost as determined by its orders; to protect the public safety from transportation and gas pipeline related accidents; to oversee the energy facilities siting process; and to ensure that residential ratepayers' rights are protected under regulations [23]."
>
> - Massachusetts statute

These type of goals are not just limited to Massachusetts similar statute can be found for regulatory bodies of other states.

> "... shall furnish ... service [which] shall promote the safety, health, comfort and convenience of its patrons..." [24] - Illinois statute

In essence, state level regulatory bodies try to oversee the following main areas

- **Regulate Energy Rates:** As we have said before utility companies are unique in that they are monopolies but at the same time society is heavily dependent upon electric energy. Due to this situation in many states electricity prices not decided by the electric utility companies, instead a regulatory body decides the rates. For instance in the state of Massachusetts, the rates and revenue division of the department of telecommunication and energy does this. Usually the price of electricity is decided on a "rate of return" basis, with this method electricity rates are decided by the government based upon the profit margin that they believe the electric utility company is entitled. Another method used in some places is "price cap regulation". Price cap regulation places a ceiling on the price utilities can charge for services, but not for profit [25].

- **Energy Production and Reliability:** Overseeing, electricity demands, load levels and power generation capacities. This is necessary to prevent disruption in service. In Massachusetts the power and siting divisions of the Department of Telecommunication and Energy looks into these issues

- **Enforcement of Utility laws:** Utility companies are required according to the law to take upon themselves the obligation of guaranteeing service to customers. For instance in the state of Massachusetts, the consumer and legal division of the Department of Telecommunication and Energy see to it that the utility companies abide by these rules. The utility laws in this area have changed since the passing of the 1992 federal "Energy Policy Act" [25]. This law has removed some of the restrictions that utility companies had to abide by. This deregulation took place in order to promote increased competition in the industry. The topic to of utility deregulation is hotly debated issue and further elaboration on it is beyond the scope of this paper.

3.1.2 Federal Level Regulation

In 1977 the U.S. Department of Energy created the Federal Energy Regulatory Commission (FERC). The FERC was given a mandate to enforce wholesale electric rates that private power companies charge electric-coops[1] and wholesale customers. In addition to this, the FERC also oversees interstate power trade and transmission access, and also the licensing of hydroelectric projects.

Despite the importance of the role that the FERC plays in regulation, little has it to do with utility laws that deal with trade between utility companies and consumers. For this reason from this point of view, it is unnecessary to delve into the working of the FERC.

3.2 De-regulation of the Electric Industry

Until the early 1980s, the American telephone market monopolized by one utility company, American Telegraph and Telephone more commonly known as AT&T. However by 1990, the AT&T's monopoly was broken. The regional divisions (Bell Pacific, GTE, NYNEX, Bell South etc.,) of the AT&T company were spun off as independent companies. It was however not long before companies like Sprint and MCI started to compete with AT&T by laying out new long distance lines. This resulted in the regional companies providing long distance telephone service to their customer, from a company of the customer's choice. This resulted in the opening up of the US long distance telephone market to competition. This drastic de-regulation of the telephone market resulted in numerous consumer benefits such as lower costs, better service and newer technologies. When the government saw how the consumer was benefiting through the deregulating the telephone market, they subsequently realized that regulation was being counter-productive. They had realized that market forces and competition could result in better benefits than through regulation. This realization started a wave of effort to de-regulate the electric industry.

The goal of the government was to create a competitive free market system where the electricity prices are controlled by the market and not by a regulator body. In order to do this the government had to force a breakup of ownership. Before the de-regulation of electric industry, companies that sold customers electricity owned both the power plants and the distribution lines that connected the customer to the power plants. In situation where the electric was not able to meet the customers demand through it's own power

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[1] An Electric-Coop is a group of operators who deliver power, that is purchased from other sources to the ultimate end user-whether it is a home, business, industry or farm

plants they do following. The electric company would buy electrical energy in the wholesale market from a third party power plant and sell it to the customer just as if it came from one of their plants.

Before 1978, even the whole sale market was regulated. The first steps in de-regulating this market started in 1978, when the Public Utility Regulatory Policies Act (PURPA) was passed [26]. PURPA had made it possible for non-utility generators to enter the whole sale power market. Non-utilities are privately owned companies that generate power for their own use. Though these companies could not sell directly to customers, they could sell excess electricity in the whole sale market to distribution companies that had customers. PURPA stipulated that electric utilities had to interconnect with and buy power offered by any non-utility company that meet certain criteria set by the FERC.

The Public Utility Holding Company Act (PUHCA) of 1935 had created the first utility monopolies by breaking up interstate holding companies. They were then required to the divest their holdings until each company consolidate there system in a certain geographical area. In 1992, the Energy Policy Act (EPACT) succeeded in opening up transmission networks by exempting certain non-utilities from the PUHCA regulations [26]. In 1996, the FERC issued an order that expanded EPACT to all non-utilities remove the qualifying restrictions that were set in PURPA. It also required that utilities establish electronic systems to share information about transmission capacity. This attracted more non-utilities into the power trade business and succeeded in increasing competition.

At the end of 1996, 3,195 electric utilities existed in the United States [27]. Out of this, approximately 700 utilities generated power. A majority of the rest consisted of companies that were exclusively distribution companies. These distribution companies purchased power in the wholesale market and distributed it over it's own lines to be sold it's customers.

3.2.1 De-regulation and Ownership issues

By deregulating the electric industry, the government hopes to inject more competition into the market place. They hope that more competition in turn will result in more innovation, cheaper prices and better customer service. However, as more states are forcing companies to split ownership of distribution networks and generation. Ownership of the electrical infrastructure is becoming more fragmented, as a result of the deregulation. With the de-regulation of the industry well underway, now a company that owns the distribution lines must open them up. So that any power plant can use them to transmitted electricity to a customer who is interested in buy electricity from it. This open electricity market gives customers a choice of where they would like to purchase their electricity.

Despite many benefits that are to come through deregulating the electric industry, the issue of power quality maintenance and electrical pollution seems to have been over looked. Customers in the local distribution networks may purchase electricity from different vendors but they are all still vulnerable to the effects of electrical pollution. At the same time the competitive nature of electric companies in a de-regulated industry will make them more unwilling to spend money on curtailing power pollution. The de-regulation of electric industry raises a number of issues about curtailing electrical pollution. Given below are examples of some:

1. Electrical pollution is a long-term problem, and is expensive to curtail. Given this who will bear the costs of curtailing it, in a cost competitive marketplace?

2. With fragmented ownership now who is responsible for monitoring harmonic pollution in distribution lines.

3. Who is liable for the damages caused by harmonic/electrical pollution?

4. Till now electric companies have pooled together research effort through organizations such as the Energy and Power Research Institute (EPRI). Now due to competitive pressure companies will be less willing fund collective long-term research.

3.3 The Lack of Anti-Pollution Laws

Coming back to the issue of curtailing electricity pollution. Let us look at the following scenario, a consumer places a request for electric service at his utility company. The distribution company provides this service to the customer, since due to regulation the company is obliged to provide service. Now the customer has the need to connect a non-linear load (e.g., electric battery charger for his electric automobile) to his power supply. As we know from chapter two the moment the consumer connects his device to the power grid, harmonic pollution is going to be injected into the power stream. Since in most cases multiple consumers are feed off the same line, the harmonic pollution just injected in by the first customer is going to start affecting equipment belonging to other customers. In addition to this as we know harmonic pollution will also start affecting the equipment belonging to the utility company itself. So why can not the utility company stop the customer from doing this? In order to understand why utility companies are pretty much helpless in stopping harmonic pollution, we have to look at the legal grounds that the company is standing on.

3.3.1 Liability laws and Harmonic Pollution

As we have said before electricity is an energy product. Electric utility companies provide the service of supplying electricity that meets their customer's needs. Hence, the relationship between an electric utility company and its customers is governed by trade laws. According product liability laws consumers can sue manufacturers for damages caused by the sale of defective products (in this case degraded power quality). Liability cases abide by the liability law. The following are the three main categories of liability laws

- **Product liability laws has evolved from two bodies of law -- contracts and torts:** Contract law provides the rules for ascertaining the legal responsibilities of parties to formal agreements, including contracts for sale of goods (in our case that would be electric power). Tort law provides the rules for determining whether a person has acted negligently towards someone to whom he owes a duty of case, independent of any contract, and whether that negligence caused injury or property damage to others. [29]

- **Negligence Standard:** Manufacturers must use reasonable care to avoid flaws in the manufacturing process that result in production of a defective product (a defective products is one that does not meet the manufacturer's own specifications.) [28]

- **The Strict Liability Standard:** Strict liability applies in the manufacturing defect context when a product is defectively made, and the defect renders it dangerous to an extent beyond that which would be expect by the customer. [28]

Liability laws were first drafted so that manufacturers could be held accountable for their products. This was done in order to protect customers. Given below is a example of a product liability law suit that received immense media publicity.

"On February 27, 1992 79 year old Stella Liebeck spilled a cup of coffee that she had purchased from McDonald's while she was adding cream and sugar. The 170 degree coffee seared her skin. By the time she reached the emergency room she had second and third degree burns. Later during the trial, the jury listened to burn experts and saw graphic pictures of Liebeck's injuries. McDonald's executives who testified

described the burns as "trivial matters" and admitted that McDonald's had received over 700 "hot coffee" complaints prior to Liebeck's injuries. Liebeck eventually was awarded $2.7 million dollars in punitive damages." [28]

3.3.2 Can not act against perpetrators

A majority of courts in this country uphold the view that electricity is a product the moment it passes through the consumer's meter. Now, since electricity is like any other product its' trade will be governed by the trade laws such as product liability laws. Hence, any damage caused by the product being trade to customer is a liability case, just like the McDonalds coffee case. When it comes to harmonic pollution electric utility companies are in a fix due to product liability laws. Electric utility companies are liable for the degradation in power quality, however they are not the cause of it. This gets even more complicated in situations where different customers purchase electricity from different suppliers but are connect by the same distribution company. In any type of liability case, the injured party (the utility company/other customers) must established three basic facts [6]

- There was an injury (this can be to either person or property.)
- An event to place
- There is a causal link between the stated event and the injury.

Let us address the first point it is possible to show that damage was caused, but this requires that we wait till the harmonic pollution will actually damage equipment. This is unacceptable since it opens the utility company up to large liabilities due to dames to other customers and itself. It is possible to prove that potential damage will happen but it will be too expensive and take too much time and effort in a court of law. The next two points are essentially the same we need to prove that a particular customer is at fault to injecting harmonic pollution and it is this harmonic pollution that lead to a certain damage or is potentially damaging. In order to prove these two points the utilities must monitor individual customers for harmonic pollution, but this would lead to the following problems.

- **Economic factors**: Given that non-linear loads are in widespread usage, this would require a large amount of investment on the utilities' behalf in monitoring equipment and manpower. This, additional expense which in turn will be passed onto customers, hence leading to higher electricity prices.
- **Legal factors:** Once a utility company isolates the polluter, it will then still have to prove in a court of the law that polluter is liable to the damages and potential damages that will be caused by his actions. Given that there are no anti-pollution laws created to prevent harmonic pollution. This usually leads to prolonged legal arguments between the utility company and the polluting customer.

Given the problems facing the utility companies they are trying to curtail harmonic pollution by taking the polluter to a court of law, it is unlikely that they will succeed. With most liability cases related to electricity there are many unresolved questions such as "are electricity by-product, such as stray voltage, leakage current and harmonic pollution "products" that are subjected to strict product liability? As of now courts in the United States have been unable to come to a uniform resolution of that issue as you can see in the below statement issued by one U.S. court.

> "The most interesting legal and factual question will focus on whether the allegedly damaging electricity was so "defective" as to be "unreasonably dangerous defect" in context of electricity. The Court will propose, however, that if the defect established by the

> [consumer] could have been mitigated most economically by [the consumer's] business varied only minimally from the normal current, for example, and occurred only rarely -- then the defect might not be sufficient to render the current unreasonably dangerous." [28]

As we see most of the work that the government does is in the name of consumer protection. Hence most utility laws are structured around protecting the consumer from the utility companies but none against other customers. As fore liability laws current laws only allow action to be taken after damage has occurred due to pollution, no pollution prevention laws are enforce like those for environmental pollution. Hence, there is a need for laws to control harmonic/electric pollution, but how will such laws come into existence?

Electricity is resource just like air. If we look at the nature air is not more than a mixture of gases in certain proportions. Just as all living beings need air for their existence, electricity is necessary for all of societies day to day needs. By polluting the atmosphere we have upset the balance eventually hurting ourselves and other species. We had to learn this lesson the hard way. Harmonic Pollution as we have mentioned before has the potential to disrupt the way society works. This type of comparison between air-pollution and Harmonic/electric pollution may seem to unconventional, the main reason being that air is something that is so fundamental to life some that we take for granted. The same will be the case with electricity we are becoming more and more dependent by the day upon electronic appliances such computers, phones, medical equipment. The1965 Northeast blackout highlighted our dependence upon electricity and electrical infrastructure.

Chapter 4 Technology Proliferation and Pollution

The human race has the tendency to adopt new technologies that bring about an improvement in living standards over time. This adaptation results in technological proliferation. However, proliferation of new technologies is also resulting in increasing problems due to pollution. The industrial revolution brought about the rapid development and progress through technological proliferation. However, along with progress came environmental pollution, which in turn lead to devastation of biological ecosystems. We are now again seeing a similar proliferation of new technologies. The new electrical and electronic technologies that we are adapting are leading to increases in harmonic/electric pollution levels. In this chapter, we shall look at how proliferation of polluting technology in the past has affected the environment. We will than try to see if the similar relationships exists between technology proliferation and pollution in electrical systems.

4.1 A Historical Look At Air Pollution

Most of the earliest forms of pollution in the pre-industrial era were from burning fuels such as coal and wood. Some of the places that were most affected were areas with large urban population, such as London. Given below, are some of the earliest recorded pollution incidents.

- During the reign of Edward I (1272-1307) there was recorded a protest, by the nobility, against the use of "sea" coal. In the succeeding reign of Edward II (1307-1327) a man was put to the torture ostensibly for filling the air with "pestilential odor" through the use of coal [30].

- Under Richard III (1377-1399) and later under Henry V (1413-1422), England took steps to regulate and restrict the use of coal, apparently because of the smoke and odors produced by its combustion. The earlier action took the form of taxation, while Henry V established a commission to oversee the movement of coal in the City of London [30].

- In 1661, a notable pamphlet published by the royal command of Charles II. It consisted of an essay entitled "Fumifugium; or the Inconvenience of the Aer and smoke of London Dissipated; together with some Remedies Humbly Proposed", written by John Evelyn, one of the founding members of the Royal Society. It is unfortunate the author's seventeenth century style attracted more attention in the twentieth century than has the content of his paper. Evelyn clearly recognized the sources, the effects and the broad aspects of the control problem to an extent not far surpassed at the time except for the detail for technological terminology [30].

4.1.1 The Steam Engine and the early Industrial Era.

The external-combustion/steam (fuel is burnt in an external furnace that heats a boiler which in turn generates steam that powers the engine) engine played a vital role in the industrial revolution. In the1690s Thomas Newcomen, a British engineer built the very first atmospheric steam engines [31]. However, it did not find acceptance until 1776 when James Watt had come up with innovations to improve the efficiency. This technology enabled us for the first time to use fossil fuels to power machinery. In the years to come, this technology proliferated as it found use in transportation (Steam locomotive, Steam Ships) and factories (Power Mills).

During the industrial revolution (1700s - 1930s) most of the world's air pollution was due to the usage of coal in external-combustion engines. The smoke that results from burning coal consists of heavy particular

matter, Sulfur Dioxide and Carbon Monoxide. All of which are dangerous to human health. In 1819, the smoke nuisance in Britain caused sufficient public concern that a Select Committee of the British Parliament appointed to study and report upon smoke abatement [32]. In 1881, the cities of Chicago and Cincinnati had passed the first air pollution statutes in the United States. By the 1900's, the smoke pollution from factories and locomotives had reached dangerous levels in industrial cities. Many county governments started to pass laws in order to curtail air pollution.

4.1.2 The Internal-Combustion Engine and the Automobile Era

In 1897, Rudolf Diesel invented the internal-combustion engine [33]. By the 1920s, the external-combustion engine was being replaced by the more efficient internal-combustion engines (i.e., engines such as the ones found in automobiles). In internal-combustion engines the fuel (usually a liquid fuel such as diesel or gasoline) is ignited inside a closed chamber, subsequently the hot expanding gases that result from the ignition actuate a piston. This process converts the chemical energy in the fuel into mechanical energy.

The design of the internal-combustion engine eliminated the need for a separate fuel furnace and boiler. This made it smaller than an external-combustion of equivalent power. The internal combustion engine was also more efficient in converting the chemical energy in fossil fuels into mechanical energy. These engines were cheaper and more efficient, hence found wider acceptance. The invention of the internal-combustion engine brought about a new age of machines that were less polluting, more efficient and more powerful compared to their predecessors. Hence, they found widespread usage in many applications. One such application is the automobile.

Table 4-1 Automobile Population and Total Emission Trends

Year	1930	1940	1950	1960	1970	1980	1990
Vehicle Population [34] (millions)	23.04	27.46	43.256	66.58	98.136	139.83	179.29
Per Capita Miles Traveled [34]	-		3,029	3,994	5,440	6,772	8598
Vehicle CO Emissions (thousand tons)[35]	-	30,121	45,196	64,266	88,034	78,049	57,848
Vehicle Volatile Organic Compounds Emissions (thousand tons) [35]	-	4,817	7,251	10,506	12,972	8,979	6,313

The coming of the automobile brought about a revolution in our way of living. Suddenly the transportation became personalized. To get an idea of how fast society adopted this technology consider the following, between the years 1920 and 1925 car sales shot up from 1,905,560 (total registered vehicles 8,131,522) to 3,735,171 (total registered vehicles 17,481,001) [34]. This growth was possible due to people such as Henry Ford who invented the assembly, which in turn helped improve mass production of goods. In the 1940s vehicles increased from around 27.4 million to around 43.2 million part of growth was spurred by World War II. After World War II the governments investment in infrastructure such as the inter-state highway system helped spur car sales even more. Between 1950 and 1990 the vehicle population of the United States, increased more than four folds from around 43 million to 179.29 million (table 4-1). In 1999, the three largest (Revenue wise) corporations in the world were automobile manufactures. They had a combined revenue of around $460 billion [36]. There are three oil companies (Exxon, Shell and BP Amoco) and five automobile manufactures (General Motors, Ford, Diamler-Chrysler, Toyota and Volkswagen) in the list of the 20 largest companies of the world [36]. In the last century, the automobile industry has been a major

driving force behind the economic progress of most of the developed nations, and the backbones of their economy.

The biggest driving force behind the proliferation of automobiles is the convenience that they give us in our day to day lives. Unlike the expensive, cumbersome steam locomotives of the past, cars are affordable. If it were not for cars and roads, suburban America would have never existed. All these consumer advantages lead to the proliferation of the automobile and the personalization of transport. However, despite all the advantages that the automobile provides us, it never the less is a polluting vehicle. The internal-combustion engine used in automobile is the primary cause of air pollution. The automobile population of American has emerged as the primary contributor to most air-pollution.

The earliest signs of automobile pollution showed up in places with high vehicle density, such as Los Angeles. In Los Angeles smog started to appear in the 1940s. Despite the lack of effort on the government's part, research on pollution was going on in the academic world. Some of the earliest air-control research took off during this period. In 1948, the first National Air Pollution Symposium in the United States was held in Pasadena, California [37]. Most of the early effort to control air pollution was done by the local and state governments. In 1952, the state of Oregon passed legislation to control air pollution [38]. This was the first state government to do so. However, much of this effort was unsuccessful, since pollution continued to grow. In 1967, the federal government facing public outrage finally took action. In 1967, congress passed the Clean Air Act [37].

4.2 The Electrical Ecosystem

4.2.1 Proliferation of Electrical Technology

In 1886, George Westinghouse started the Westinghouse Electric Company in Pittsburgh, Pennsylvania. He had bought the rights on the patents to Nikola Tesla's system of alternating-current dynamos, transformers, and motors [39]. There was an early power struggle between Thomas Alva Edison's direct-current systems and the Tesla-Westinghouse alternating-current approach, which the latter eventually won. In 1893, Westinghouse used Tesla's system to light up the World's Columbian Exposition in Chicago []. His success there helped him win the contract to install the first power generation equipment at Niagara Falls, which bore. This project carried power to the city of Buffalo by 1896 . In the years to come, electrical systems based on alternating current proliferated rapidly. Westinghouse manufactured a complete line of machinery and products used to generate, transmit, distribute, and control electricity. Over the years, Westinghouse became a major supplier to the electric utility industry. The constant advances made in the field of electrical engineering and the resulted in an increasing number of applications for electricity.

Proliferation of electrical/electronic has not slowed over time, in fact it has increased. As society is adopting and using technology at a faster rate than ever before in its history. Advances in semiconductor and communication technology are a major reason. For instance, the first IBM PC came out in the year 1982, and at the turn of the century the Intel corporation (the company that make the microprocessor the PC) plans to sell around 100 million microprocessors [40]. Personnel computers now out sell televisions in the U.S. Devices are becoming more complex and at the same time cheaper. To understand the level of technological adoption take a look at this observation made in 1994 by Prof. Nicholas Negroponte of the MIT Media Labs in his book, "Being Digital".

> "Computers are moving into our daily lives: 35 percent of American families and 50 percent of American teenagers have a personal computer at home; 30 million people are estimated to be on the Internet; 65 percent of new computers sold worldwide in 1994 were for the home; and 90 percent of those sold this year are expected to have modems

and CD-ROM drives. These numbers do not even include the fifty microprocessors in the average 1995 automobile, or the microprocessors in your toaster, the thermostat, answering machine, CD player, and greeting cards."

4.2.2 Technology Proliferation and Pollution in an Electrical Ecosystem

Everyday we can see the ongoing proliferation of electrical technology taking place, but how is this affecting the electrical ecosystem? In chapter 2 we had looked at some of the effects of harmonic polluction. We have also seen that the most systems that cause electrical pollution are new devices such as ASDs, computers. At the same time the equipment that are the most sensitive to electrical pollution are also new technology devices, such as computers and microcontrollers. However, unlike the case of automobile emissions where the effects of air pollution can be felt (smog), in the case of harmonic pollution we cannot see, smell or feel the effects of electrical pollution. Nevertheless, electrical pollution is causing damage as we have described in chapter 2.

Inorder to obtain a better idea of the correlation that exists between the proliferation of electical technology and electrical pollution let us take a look at the following. In 1997 a survey was done on a local distribution network in a New England town. The table below (table 4-2) provides a list of the various types of consumers and their approximate load capacities (consumption capacity) that were surveyed. As you can see the customers surveyed represent a wide variety. In all it included eight industrial customers, one university building, one large supermarket and one large apartment building. Also included were twelve feeders at ten substations on the utility side.

Table 4-2 Consumer Profile [42]

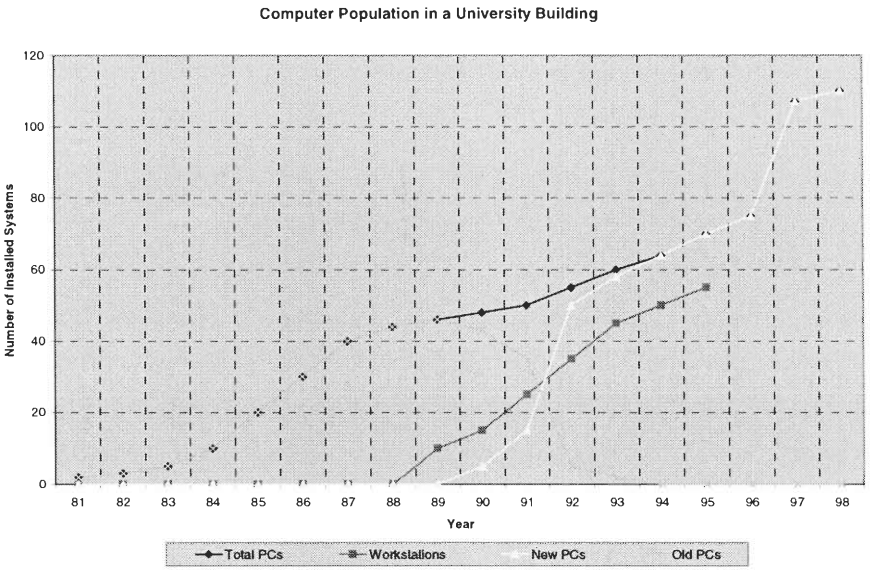
Consumer	Power Consumption (kVA)
Forging and Casting	620
Automotive Electronics	120
Printing	180
Extruded Plastics	36
Electronic Packaging	150
Asphalt	415
Hospital Building	85
Rubber Products	300
Apartment House	450
University Building	60
Pressboard Objects	2700

Supermarket	300

Inorder to correlate the proliferation of nonlinear loads and the harmonic levels over time. The survey tracked the quantity and type of loads installed over a period and then correleated it with the increase in harmonic emissions and the increase in voltage/current distortion. To do this they conducted a survey of a university building, a facstory (Pressboard processing plant) and a large supermarket.

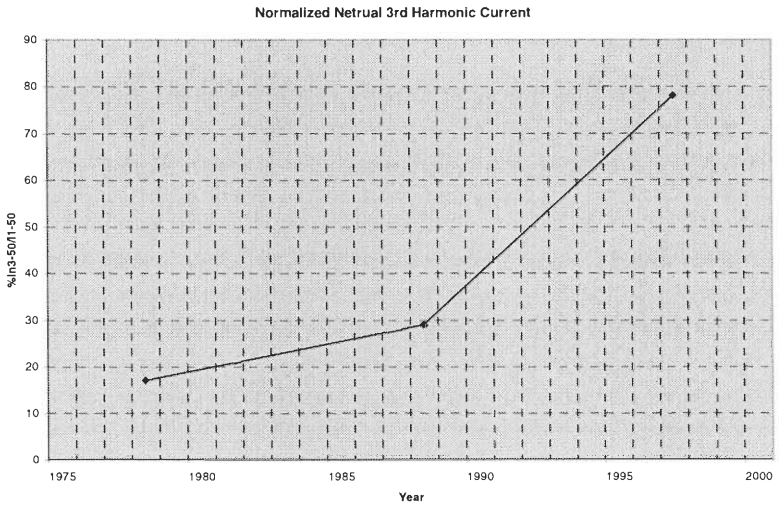
The univeristy building studied was supplied at 208/120V and had a 66kVA load. The loads were mostly fluorescent lights, personel computers (PCs) and computer workstations. Fig 4-1 below depicts the total new PC and population in the building between 1980 and 1997. They looked at computers in the building because they are nonlinears loads due the rectifiers that they use. In the study they found that there was a correlation between the installation of new PCs and computer workstations and an increase in the 3rd harmonic neutral currents. Fig 4-2 dipicts the ratio of the means of the 3rd and 5th harmonic current. As we can see that between 1987 and 1997 that the rate of increase of the 3rd harmonic currents distortion shot up this coincides with the increased installation of new nonlinear loads such as new PCs and workstations.

Figure 4-1 Computer Population in a Univesity Building [43]



Another customer included in the study was a press-board processing factory. The factory had a maximum load capacity of 2700 kVA. This included motors that drove a variety of equipment such as pulp drivers, agitators, water circulators etc. In studying this consumer, they noticed a correlation between the introduction adjustable speed drives and the raise in THD in both current and voltage [43].

Figure 4-2 % 3rd Harmonics in Neutral Current



The data measured and reported in the survey consisted of mean (50% probability) and max (99% probability) values for THD_v (total harmonic distortion in voltage), THD_I (total harmonic distortion in current, refer section 2.3.1), the third, fifth and seventh harmonics in the voltage and current. AS can be see from table 4-3 the rate of increase in distrortion has been on the rise at the the end-user. Similar increases were also found on the utlity side (when measured at substations). From the end-user data in table 4-3 we can see the current distortion is much worse than the volatge distortion. However both mean THD_v and mean THD_I are within tolerable limits (<5%). But if the current rate of increase keeps up this will not be the case.

Table 4-3 % Rate of Distortion Increase per Decade at Utility and Consumerends [44]

	Utility End		Consumer End	
	50% prob	**99% prob**	**50% prob**	**99% prob**
THD_v	0.30 - 0.85	0.75 - 1.20	0.20 – 1.00	0.20 – 0.80
V_3	0.25 - 0.75	0.50 - 0.75	0.28 – 0.50	0.40 – 0.60
V_5	0.25 - 0.50	0.55 - 0.80	0.28 – 0.50	0.40 – 0.60
V_7	0.10 - 0.25	0.15 - 0.20	0.15 – 0.45	0.10 – 0.65
THD_I	2.50 - 3.60	2.90 - 3.80	0.25 – 3.60	2.90 – 3.80
I_3	1.30 -1.50	1.70 -1.90	0.20 – 0.40	0.90 – 6.40
I_5	1.50 - 2.10	3.10 - 3.60	0.35 – 3.00	0.50 – 5.80
I_7	0.30 -0.80	0.40 - 1.10	0.10 – 1.50	1.20 –3.10

Raise in pollution is increasing. Study done in Japan states. Study done in New England states.

The market for products and services to clean up power is around $1.2 billion and escalating [].

4.3 Harmonic/electric pollution Vs Automobile Pollution

Until now, the electric power industry has been taking the lead in the effort to curtail harmonic/electric pollution. This spearheading effort has lead to organizations such as the EPRI, to focus on technical solutions to help in curtailing harmonic/electric pollution. However, harmonic/electric pollution is a vast problem that involves consumers, equipment manufactures and distribution companies. In the previous chapter, we have looked at some of the problems that the electric power industry is facing in the effort to curtail power pollution. We can safely say that mere technological solutions can not help in addressing the numerous problems faced in curtailing electric power pollution. These problems raise a number of questions such as,

1. Who is to blame for harmonic/electric pollution, the consumer or the equipment manufacturer?

2. In the competitive marketplace who is to bare the economic burden of curtailing harmonic/electric pollution.

3. Can the existing product liability laws be helpful in curtailing polluters?

4. In order to curtail harmonic/electric pollution, do we need new anti-pollution laws for electrical pollution?

5. Who will oversee the creation these laws?

6. Who will enforce new laws?

In order to answer these and other questions the industry will have to rethink their approach to solving this problem. As we have seen before pollution caused by technological proliferation is not unique to electrical pollution. It has happened before, despite this people have found methods to curtail pollution as in the case of air pollution. Much can be learnt by studying how air pollution curtailment. The Automobile emission control effort would be the best case to study. Air pollution caused by automobile emissions power quality degradation caused by electrical/harmonic pollution are similar to each other in the following ways.

1. In both cases, the proliferation of polluting technology causes pollution.

2. The polluted resource is shared between the polluters and the non-polluters.

3. The polluted resource (electricity and air) is essential for our existence.

4. The polluting technologies (electrical equipment and the internal combustion engine) are essential for economic progress in both cases.

5. Both pollution problems are long term problems there are no quick fixes.

Figure 4-3 U.S Vehicle Population and Per Capita Miles Travelled[1].

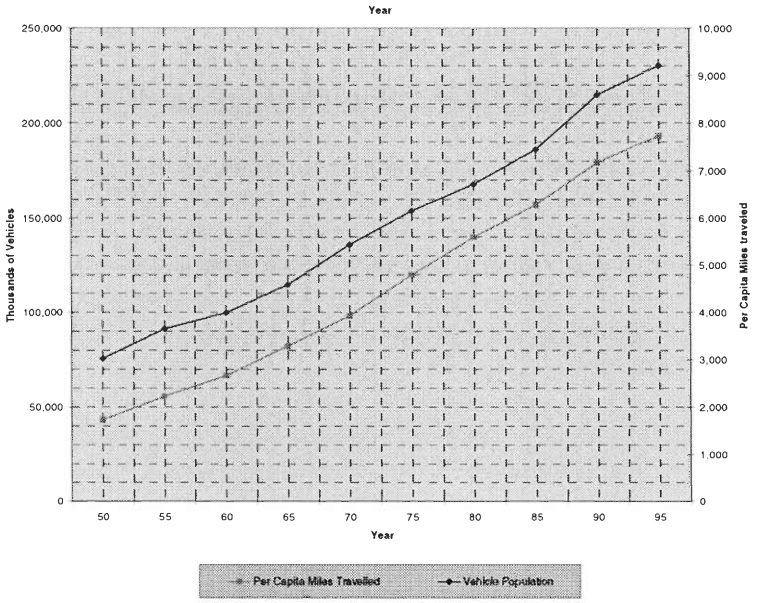
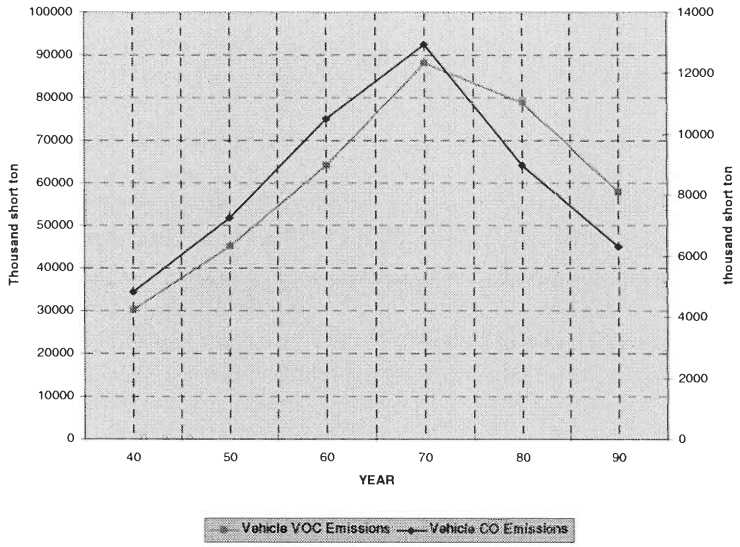


Figure 4-4 CO and Volatile Organic Compound Vehicle Emissions, 1940-1990[2].



[1] U.S Department of Transportation [45].

[2] U.S Environmental Protection Agency [54].

The success meet in controlling automobile emissions is another important reason to look at it in detail. In the past 30 years automobile emissions control has made significant progress in reducing emission levels. From the above two charts (fig 4-3 and 4-3) we can notice that automobile emissions such as cabon monoxide and Volatile organice (we shall see more about types of emissions in the next chapter) compounds have increased proportionally to vechicle popultaion until 1970. However, since 1970 the emissions have been on a downward trend. This is despite the increase in both the vehicle polpulation and the per capita vehicle miles being traveled. This is a significant achievement since it proves that the relationship between technological proliferation and pollution levels can be broken. As we shall see in the next section this improvement in air-quality is due to the governments involvement in the effort curtail automobile emissions.

Chapter 5 Curtailing Automobile Pollution

5.1 Automobiles pollution

Automobile pollution is possibly the best example for us to understand pollution control. Since we many similarities. Harmonic/electric pollution just like automobile pollution is being brought about by societies rapid adoption of new technology. The growth boom in the electronic and computer industry is bringing about a sea of change in the way society lives. This massive adoption of new technology has at least started since the 1970s, but the effects of harmonic/electric pollution are becoming evident only in this decade. Also as we have mentioned before harmonic/electric pollution is a understood by technologists but not by politicians

The automobile is the single largest contributor to air pollution in many cities. This pollution is because of the collective emissions from the usage of millions of vehicles. It was the early 1950s, when Dr. Arlie Haagen-Smit made the connection between smog and automobile exhaust [46]. Dr. Haagen-Smith was a biochemist at the California Institute of Technology, researching the affect of sunlight upon automobile emissions. He determined that the excessive traffic found in the Los Angeles was to blame for the smoggy skies over the city.

Automobiles are, powered by burning fuel (gasoline or diesel) in their engines. This process essentially converts chemical energy into mechanical energy. A mixture of hydrocarbons (i.e., compounds that are made up of hydrogen and carbon atoms) is used as a fuel to power automobiles. In a "perfect" engine, the oxygen in the air would convert the carbon in the fuel to carbon dioxide[1] and the hydrogen into water. In reality, this combustion process in not perfect and hence results in many other byproducts, such as Hydrocarbons, Nitrogen Oxides and Carbon Monoxide. These byproducts are harmful to humans and are hence pollutants. Two other sources of pollution from an automobile are evaporative emissions and refueling losses.

- Hydrocarbons (also known as Volatile Organic Compounds or VOC):
- Nitrogen Oxides/NO_x:
- Carbon Monoxide (CO):
- Sulfur Dioxide (SO_2):
- Carbon Dioxide[1]:

This type of pollutant identification is necessary early in the process. Since each type of pollutant may need different methods of curtailment. This is similar to the classification done with harmonic/electric pollution.

---

[1] All though carbon dioxide does not directly effect human health. The U.S Environmental Protection Agency (USEPA) has started to view carbon dioxide as a pollution concern. This is due to its potential contribution to global warming.

For instance, there are separate methodologies to curtail harmonics in the power stream and voltage surges and swells.

5.2 The Effects of Automobile Pollutants

Each contributing chemical despite coming from the same exhaust affects us in different ways just as different frequencies of harmonics affects different systems. Given below are the effects of the four major chemical pollutants found in automobile exhaust.

- **Hydrocarbons/VOC:** As explained before, in a perfect engine when fuel molecules burn they release energy, they also release Carbon dioxide and water as byproducts. In reality when fuels burns in an engine some molecules do not burn and some burn partially. This leads to the release of hydrocarbon byproducts. Hydrocarbons lead to the formation of secondary pollutants such as tropospheric ozone (ground level ozone) and other major components of smog [48]. This ozone then causes lung damage, aggravation of lung problems and the irritation of eyes. Some hydrocarbons are, also known to be toxic and carcinogenic .

- **Nitrogen Oxides (NO_x):** Nitrogen Oxides form when nitrogen and oxygen atoms react in the extreme environment found inside an engine. Nitrogen Oxides like hydrocarbons are help create secondary pollutants such as ground level ozone [48].

- **Carbon Monoxide**: Carbon Monoxide results from the partial combustion of fuel. Carbon dioxide is toxic to humans since it reduces the flow of oxygen in the bloodstream. CO can kill at a concentration of around a 1000 parts per million (ppm). Levels that are around 120 PPM per hour are considered to be a serious level [47].

- **Carbon Dioxide:** Even though carbon dioxide does not directly impair human health, in the recent year the U.S.E.P.A has started viewing it as a pollutant. The reason for this that carbon dioxide in the atmosphere is aids in global warming, since it traps the earth heat (green house effect).

- **Sulfur Dioxide:** Sulfur is a common impurity found in crude oil. If this sulfur is not eliminated during the refining process it ends up in automobile fuel (mostly diesel). This sulfur reacts with oxygen inside an engine to result in sulfur dioxide when the fuel combusts. SO_2in the atmosphere leads to acid rains. Its corrosive nature also has significant affects on human health [48].

Of the four major pollutants found in Automobile exhaust, carbon monoxide is by far the deadliest. Unfortunately carbon monoxide pollution is also the largest (in terms of emitted volume, refer to table 5-1) portion of automobile pollution. In 1962, Professor McFarland of Harvard summarized the studies on carbon monoxide as follows:

> Carbon monoxide poisoning is an ever-present possibility in the operation of motor vehicles. The problem is becoming increasingly serious because of the increased density of smog and concentration of idling vehicles in the metropolitan areas. Small amounts of carbon monoxide are absorbed rapidly by the blood stream, resulting in an oxygen deficiency that may at first be unnoticed by the individual. The initial reaction to carbon monoxide poisoning consists primarily in lowered attention, difficulty in concentration and retention, slight muscular in-coordination, sleepiness, and mental and physical lethargy. [47]

Scientists have shown that the CO_2 emissions that result from burning fossil fuels can result in global warming. According to them, CO_2 emissions are building up in the atmosphere. Build up of CO_2 in the atmosphere leads phenomenon known as the "green house effect" in which the atmosphere prevents heat from radiating off the planet. This is similar in principle on how a green house operates (allows sun light in but prevents heat to leave). Over a long time (depends on how fast excess CO_2 builds up) the green house effect results in raising average temperatures worldwide, a phenomenon known as "global warming". Unlike the curtailing other types of automobile emissions curtail CO_2 may actually require radical changes in the technology that we use since we have to reduce the rate of consumption of fossil fuels. This will require action such as increasing fuel efficiencies in engines or even replacement of the internal combustion engine. Our heavy dependency on fossil fuels technology have made the job of curtailing CO_2 emissions unsuccessful till now. We shall not be discussing automobile CO_2 emissions here, since no significant curtailment has occurred in the last. This is because the claim of global warming is still an issue being debated amongst environmentalist, auto/oil industries and the politicians.

5.3 The Environmental Movement

One important aspect that we should keep in mind while talking about curtailing automobile pollution is that it cannot be solved over-night. Any process of curtailing automobile pollution has to be a continuous ongoing process. The reason for this is societies vast dependency upon the polluting technology the more pervasive the technology the harder and slower it is to change it. The electric industry is in the same position as that of which the environmentalist were in the 1960s. If they do not act at this stage then it will become more difficult and expensive to clean up harmonic/electric pollution later. The automobile industry is one of the worlds largest and hence is a driving force behind our economy. It was issues like this that were facing the government in the late 1950s, when automobile pollution started became a major problem in most U.S cities. The main problem faced by environmentalist was not technological but was political. In other words it was the federal governments' lack of political will that was preventing pollution curtailments.

Some of the earliest environmental laws were created by legislators from cities and regions suffering form the worst automobile pollution. However just as harmonic/electric pollution laws at a regional level are ineffective, so was the pollution control legislation. Hence the more widespread the polluting technology is found the greater the need for broader laws. The broader the laws the more effective it will be. The problem facing the environmentalist of the 1950s and 60s was getting the politicians to make the laws. However, since it is the people politicians, they care about the issues that the people care for. Hence, the first task in any fight form of pollution whether it be electrical pollution or automobile pollution, is to raise public awareness about the problems and potential problems.

The first thing necessary for any successful public awareness campaign is a medium of communication. By raising public awareness about we are essentially try to get people to care about the issue. The more means of communication that we have the more people the campaign can reach out to. The biggest benefit that environmentalist had in the 1960s and 70s was the television. For instance, you could write about the effects of pollution, but you would be more effective in convincing the person by showing him a picture of the effects of pollution.

5.3.1 Early Leaders

Every once in a while, an individual, or a group of individuals does something that wakes society up. In 1962, Rachel Carson a biologist of the U.S. Fish and Wildlife Service published "Silent Spring". This book brought out facts about pesticide pollution and the negligence of the chemical industry that caused it. This book better known for highlighting the role DDT usage played in disseminating the American bald eagle population. As one author stated, "Carson's book constituted the first major successful effort to alert citizens

to environmental danger and to help them think systematically and in the long term." [50]. Carson's book is worth mentioning here despite the fact that it was aimed at the chemical industry and not the automobile industry, since it helped raise public awareness about effects of industrial pollution.

By the 1960s the effects of automobile emissions were well known in the research world. Many papers had been published and many conferences about the effects of automobile emissions on air quality. However, the general public was unaware of it. However, in 1965, a young lawyer by the name of Ralph Nader published a book called "Unsafe at any speed". This book and the publicity around Nader's crusade had caught the publics attention. Nader's book was an investigative report into the practices of the automobile industry. In essence, Nader's book accused the American auto industry of negligence of basic safety in automobiles. In his book, Nader provides insight into the effects of automobile emissions on the quality of air. The most important contribution that came from Nader's effort was identifying the real perpetrator. Pollution comes about when people drive cars. In order to curtail pollution we either have to have fewer automobiles on the road, or we make the car cleaner. Since taking the former approach would lead to curtailing freedom and economic progress (by the 1960s the automobile industry had emerged as the backbone of the American economy), hence the blame lies squarely on the shoulder of the automobile manufacturer. Nader recognized this and highlighted it to the public. Naders' accused the automobile industry was willfully neglecting research and development of basic safety created a public out cry.

5.3.2 The Government versus the Auto Industry

Even before Ralph Nader launched his crusade against the automobile industry, there were people trying to fight automobile pollution. However, the general public does not know much about them. Most of these people were local government officials in areas such as Los Angeles where the effects of automobile air pollution were most felt. For instance in the 1953, the L.A County supervisor Kenneth Hahn wrote to Henry Ford II (Chairman of Ford Motors then) asking him about efforts Ford was taking to curtail automobile emissions. Ford never replied but passed on the letter to Dan Chabak of fords news division who replied as follows.

> "The Ford Engineering staff, although mindful that automobile engines produce gases, feels that these vapors are dissipated in the atmosphere quickly and do not present an air-pollution problem. Therefore, our research department has not conducted any experimental work aimed at totally eliminating these gases. [52]"

Most of this early effort had succeeded in getting automobile manufacturers to do nothing more than publish scientific papers on the effects of automobile pollution. The above is an instance of the negligent attitude of the automobile industry at that time as depicted in Nader's book. However, by 1965 the federal government start to intervene after finding that state and local authorities were unsuccessful in getting the automobile industry to listen. However, despite this the automobile industry was still unwilling to listen. As can be see Given in this exchange between Senator Robert Kennedy (D) and, General Motors executives Frederic Donner and James Roche, during the 1965 hearing conducted by the Ribcoff subcommittee. [53]

> Kennedy: What was the profit of General Motors last year?
>
> Roche**:** I don't think that has anything to do...
>
> Kennedy: I would like to have that answer if I may. I think I am entitled to know that figure. I think it has been published. You spend a million and a quarter dollars, as I understand it, on this aspect of safety. I would like to know what the profit is.
>
> Donner: The one aspect we are talking about is safety.

Kennedy: What was the profit of General Motors last year?

Donner: I would have to ask one of my associates.

Kennedy: Could you, please?

Roche: $1,700,000,000.

Kennedy: What?

Donner: About a billion and a half, I think.

Kennedy: About a billion and a half?

Donner: Yes.

Kennedy: Or $1.7 billion. You made $1.7 billion last year?

Donner: That is correct.

Kennedy: And you spent $1 million on this?

Donner: In this particular facet we are talking about…

Kennedy: If you just gave 1 per cent of your profit, that is $17 million.

An on going fight between the federal government and the automobile industry took place over the next two decades. This resulted federal level initiatives such as passing the Clean Air Act, the creation of the Environmental Protection Agency etc., in order to curtail environmental pollution (including automobile pollution). As we shall see in the rest of this chapter, much the effort to curtail automobile emissions was successful made much progress in reversing emissions by the 1990s. As for General Motors it now spends a considerable amount of money on pollution control and the environment (www.gm.com/company/environment). This change in attitude came about due to concerns over consumer black-lash, government pressure and market forces.

5.4 Results of Environmental Legislation:

The success of the environmental campaign of the 1960s had awaken the American public too the industrial abuse of the environment. The federal government hence started to look into the practices of industries such as the automobile industries. This culminated in the government taking action, in order to safeguard the environment. This effort has been an on going process spanning a period of 40 years and 7 presidents, and is still continuing.

The 1960s, can be considered the period of awaking. It was during this period that the federal government was waken up by the environmental movement. California passed the first ever legislation aimed at improving air quality. The first federal Clean Air Act was passed during this period. However, the federal government did little more than fund pollution research and other state level pollution control efforts. The states governments did much of the work during this period. There was not much work done in this period primarily due to a lack of urgency and stonewalling, on part of the automobile industry.

actions of the government. Even though a series of basic improvements in engine design helped improve air quality, they fell short in meeting the governments standards. This then forced the government to extend them by a couple of years. This marked the start of a long fought dual between the government which sets standards and the industry falling short of meeting them. The 70s also marked a coming of global competition. The oil crisis during this period had helped Japanese car manufactures. It was during this period that fuel efficient cars began to gain popularity.

Other than the imporvement in sulfur dioxide emmission levels there has not been much improvements in other areas. This is primarily due to technological problems. The current technolgy has been streached to its limits in the last couple of the years their has been considerable effort spent in finding a replacement to the fossil fuel based internal combustion engine. In other words the next stage of imporvments will need so called zero emmision vehicles to replac exiting ones.

5.4.1 Carbon Monoxide

In terms of quantity, Carbon Monoxide makes up the largest portion of vehicle air pollution. As we can see from Table 4-1, on road CO emissions (i.e., pollution due to vehicles and not industrial contributions) at their peak levels in 1970 where an estimated 88,034 tons. On-road vehicles are also the main source of total national CO emissions in the U.S since World War II. When we compare it to VOC, NO_x and CO emissions are many folds larger. However, in a span of 20 years between 1970 and 1990, CO emissions were successfully reduced from around 88 million tons, to around 55 million tons. On-road vehicles still contributor to around 61% of total national CO emissions, but this has come down from 68% in 1970. [] So how did we succeed in reducing the CO emission levels?

Table 5-1 Distribution of On-road Emissions in 1990 and 1970

Year	CO	VOC	NO_x
1990 emissions (lowest levels) (1000's of tons)	57,848	6313	7040
1970 emissions (highest levels) (1000's of tons)	88,034	7,390	12,972

5.4.1.1 CO Emission Trends:

The graph displayed in figure 4-1 shows the total on road CO emission in the U.S between the years 1950 and 1990, it also display the registered vehicle population (total number of cars and trucks) during the same period [54,34]. From this graph, we can see that between the years 1950 and 1970, the total on road CO emissions increased along with the vehicle population. However, we can see that this relationship between vehicle population and emission levels broke between 1970 and 1990. Between the 1970 and 1980 CO emissions dropped from 88,034 to 78,949 (10.3% decrease), and between 1980 and 1990 emissions fell from 78,949 thousand tons to 57,848 thousand tons (26.7% decrease). This decrease in emissions took place, despite the increase in vehicle population (total number of register vehicles) from 98,136,000 in 1970 to 179,299,000 in 1990 (82.7% increase). However, this decrease in emissions is not due to a decrease in usage. Since during the same period the average annual miles driven per car increased from 5,440 miles in 1970 to around 8,598 miles in 1980 [34]. On-road vehicle CO emissions have drop 32 percent between 1970

and 1993, at the same time fuel usage has increase approximately 50%. This decrease in CO emissions can be attributed to two factors, increase in vehicle fuel efficiency and better emission control.

In 1963, the U.S congress passed the first Clean Air Act (CAA), providing permanent federal support for pollution research and state level pollution control agencies. By 1967, the worsening pollution level forced congress to pass the Air Quality Act, which required states to establish air quality control regions. When the CAA was amended in 1970, federal involvement further increased with the creation of the U.S Environmental Protection Agency (U.S.E.P.A). The newly constituted Environmental Protection Agency was given the responsibility of setting Non Ambient Air Quality Standards (NAASQ) [55]. The establishment of national standards for emissions was the catalyst the made automobile manufactures take pollution control seriously. Table 1-2 lists the various CO emission limits set for vehicles since 1970.

Since 1970, automobile manufactures introduced the catalytic converter (1975), three-way catalyst (1981), and computer controlled engines with oxygen sensors (1981). These new technologies have helped automobile manufacture meet ever more stringent emission standards. As we can see in table 4-2, emission limits between 1972 and 1994 been driven down year after year. By doing so, the EPA has succeeded in reducing CO emissions 32% in a span of 20 years. Given below is a list of the major milestones in the federal government's effort to reduction NO_x and VOC emissions.

However, automobile manufacturers were unable to meet the 1975 limits on time. Congress had to postpone the deadline until 1977. The real effect of the standard on emissions took place after 1977. The reasons for this is that the limits applied to models manufactured after 1975, and until the older models were phased out any significant reductions would not be take place.

Figure 5-1 Total on-road vehicle CO emissions 1950-90

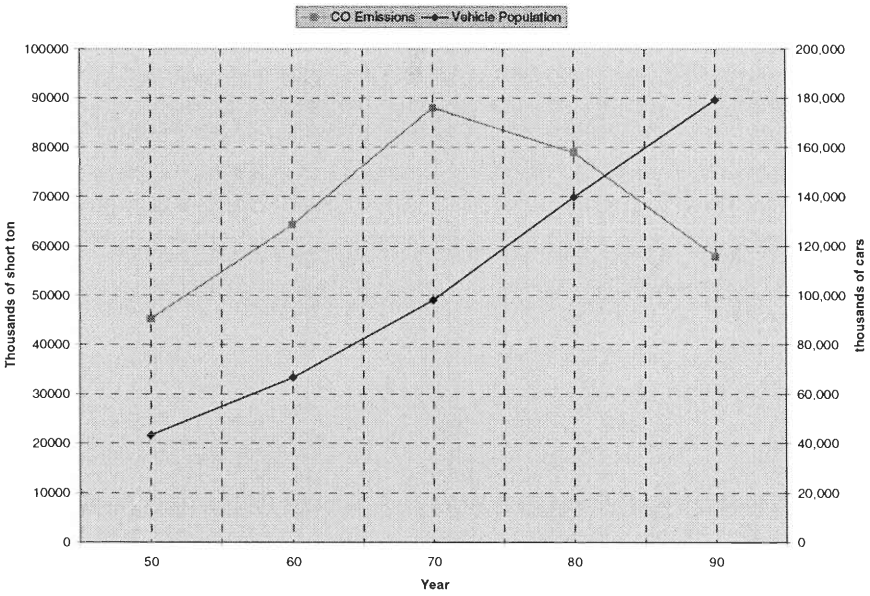


Table 5-2 Carbon Monoxide Emission Standards, 1970 to Present

	Emission Limit (grams of CO per mile) [56]	
Model Year	Light-duty Vehicles	Light-duty Trucks

1970-1971	23	N.A
1972-1974	39	39
1975-1979	15	20
1980-1993	3.4	18[1], 10[2]
1994+	3.4[3]	4.4[3]
1994+	4.2[4]	

CO emission showed a significant decrease between 1973 and 1975 as a result of disruptions in world oil markets. This exemplifies the way market forces can influence emission levels. This short-term decrease in CO emissions was also seen in NO_x and VOC emissions. During the oil crisis in the 1970s, market forces had pushed oil prices to high. This had two effects, the first was consumers started to buy more and more smaller fuel efficient cars that were mostly imported from Asia. In the1980s the auto industry attitude changed. The automobile industry began to paint itself with an environmental friendly image. This change was brought about by market forces such as competition, changing consumer demographics etc.

5.4.1.2Major CO curtailment milestones

- 1964: California required minimal emission control system. One of the first government legislation targeted at reducing automobile pollution [57].
- 1967 Congress passed the Air Quality Act, which required that states establish air quality control regions.
- 1970: The 1967Air quality Act amended and the "Clean Air Act" is adopted by Congress. Also the creation of the U.S Environmental Protection Agency (USEPA.)
- 1974: The 1970 Clean Air Act standards for HC and CO are delayed until 1978, instead an interim standard is adopted. Congress also passes the Energy Policy Conservation Act thus setting fuel economy standards [57].
- 1975: In response to the HC and CO standards, the first catalytic converters and unleaded gasoline appear [57].
- 1977: Clean Air Act amended by Congress. Auto-makers got till the year 1981 to meet CO and NOX standards and 1980 for HC.
- 1981: New three-way catalysts with on-board computers and oxygen sensors appears in new cars and help them meet the Amended (1977) "Clean Air Act" [57].

---

[1] Standard applies for 1979-1983 model years.

[2] Standard applies for 1984-1993 model years

[3] Standard applies to vehicles that have a useful life of 5 years or 50,000 miles, which ever comes first

[4] Standard applies to vehicles that have a useful life of 10 years or 100,000 miles which ever comes first

- 1983: Inspection and Maintenance (I/M) programs are set up throughout the country. This required motor vehicles to undergo emission control tests periodically to check for malfunctioning emission control systems [57].
- 1985: Emission standards for the year 1991 and 1994 set for diesel powered trucks and buses set by U.S.E.P.A.
- 1989: Fuel volatility limit set by U.S.E.P.A to reduce evaporative emissions [57]
- 1990: The "Clean Air Act" was amended by the Congress, there by requiring further reductions in the HC, CO and NOX emissions [57].
- 1992: New standard was set for CO emissions at cold temperature. Oxygenated gasoline introduced for the first time to reduce CO emissions [57].

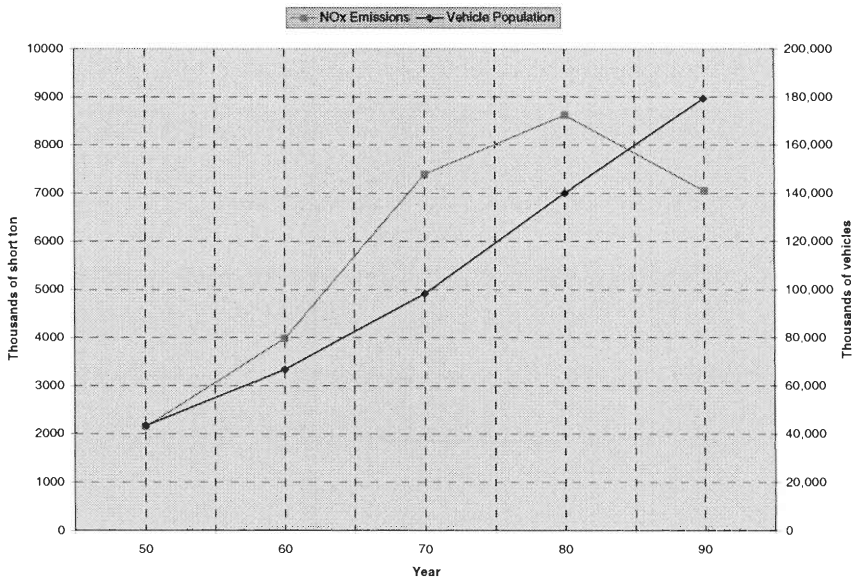
5.4.2 Nitrogen Oxides and Volatile Organic Compounds

We are grouping both Nitrogen oxides and volatile organic compounds together, because they are primary pollutants that in the presence of sunlight results in secondary pollutants such as ground level ozone. As we have seen before, the primary cause of CO emission in vehicles is the partial combustion of hydrocarbons (gasoline, diesel) in an internal combustion engine. This partial combustion also causes volatile organic compound (VOC) emissions. VOC emissions due evaporative loses are also substantial. NO_x.

5.4.2.1 NO_x and VOC emission trends

Around 1900 NO_x emissions due to transportation where insignificant. In 1920 they accounted for 5 percent and increased to around 15 percent by 1940. At the same time vehicle population increased from around 8 million to around 27 million. From figure 4-2 we can see that this relationship (as vehicle population, vehicle miles traveled, fuel usage increase emissions increase) between vehicle population and NO_x emission held steady until they peaked around the year 1978.

Figure 5-2 Total on-road NO_x emissions 1950-90



In 1900, transportation accounted for around 4% of VOC emissions of which railroads accounted for nearly all. However now the railroads account for less than one percent after reaching their peak at around 20% of total national VOC emissions [58]. Automobile contributed to a 162 percent increase between the 1940 and

1970 as can be seen from figure 4-3. In 1970 on-road emissions peaked at around 13 million tons and accounted for 40% of total national VOC emissions.

Figure 5-3 Total on-road VOC emissions 1950-90

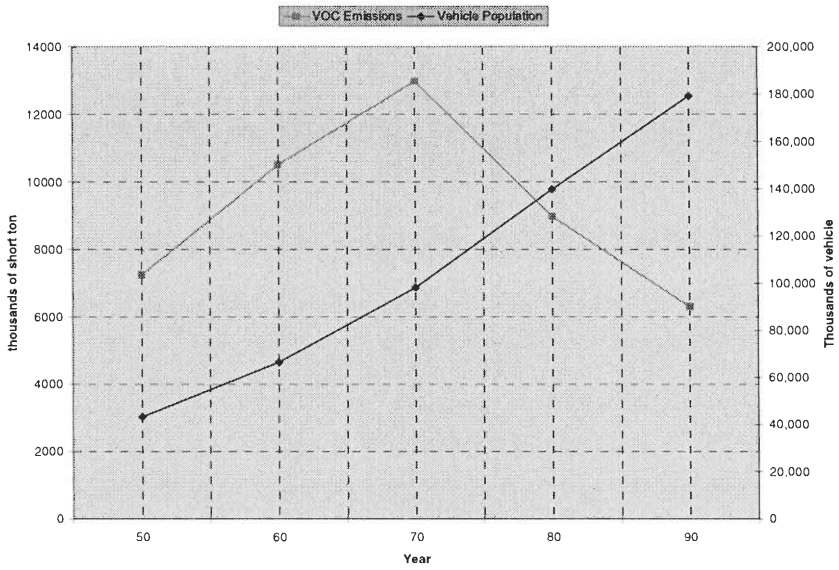


Table 5-3 Nitrogen Oxides and Volatile Organic Compound Emission Limits for Light-Duty Vehicles

	Emission Limit (grams per mile) [59]	
Model	NO_x	VOC
1972-1974	3.0[1]	3.4
1975-1979	3.1[2],2.0[3]	1.5
1980-1993	1.0[4]	0.41
1994+[5]	0.4	0.25
1994+[6]	0.6	0.31

[1] Standard applies for 1973-1974 model years.

[2] Standard applies for 1975-1976 model years.

[3] Standard applies for 1977-1980 model years.

[4] Standard applies for 1983-1993 model years.

[5] Standard applies to vehicles that have a useful life of 5 years or 50,000 miles.

[6] Standard applies to vehicles that have a useful life of 10 years or 100,000 miles.

Since its incorporation in the 1970s, the EPA has been setting limits (figures 4-2 and 4-3) on NO_x and VOC emissions from on road vehicles. These have gotten auto-makers come with a number of innovations such as, charcoal canister (to trap evaporative emissions from gasoline fuel), exhaust gas re-circulation (EGR), catalytic converters, three-way catalysts and oxygen sensors. Stricter emission limits over the years have succeeded in reducing NO_x and VOC emissions due to on-road vehicles. NO_x emissions due to on-road vehicles have reduced from 8.6 million tons to 7 million tons (18% decrease) in 10 years (1980-1990). Similarly, VOC emissions have reduced from their peak around 12.9 million tons to 6.3 million tons (a 51% decrease) in twenty years (1970-1990). Given below is a list of the major milestones in the federal government's effort to reduction NO_x and VOC emissions.

Table 5-4 Nitrogen Oxides and Volatile Organic Compound Emission Limits for Light-duty Trucks

	Emission Limit (grams per mile) [59]	
Model	NO_x	VOC
1972-1974	3.0[2]	3.4
1975-1978	3.1[1]	2.0
1979-1984	2.3[2]	1.7
1985-1993	1.2	0.8
1994+[5]	0.7	0.32
1994+[8]	0.97	0.4

5.4.2.2Major nitrogen oxides and volatile organic compound emission curtailment milestones: [57]

- 1964: California required minimal emission control system. One of the first government legislation targeted at reducing automobile pollution.
- 1967 Congress passed the Air Quality Act, which required that states establish air quality control regions.
- 1970: First major "Clean Air Act" adopted by Congress. Creation of the U.S Environmental Protection Agency (USEPA.)
- 1971: The first charcoal canisters to trap gasoline vapors are introduced in cars to reduce evaporative emissions.
- 1972: In order to meet NO_x standards auto-makers introduce "Exhaust gas re-circulation (EGR)" valves in cars.
- 1975: In response to the HC and CO standards, the first catalytic converters.
- 1977: Clean Air Act amended by Congress. Auto-makers got till the year 1981 to meet CO and NOX standards and 1980 for HC.

---

[7] Standard applies for 1975-1978 model years.

[8] Standard applies for 1979-1987 model years.

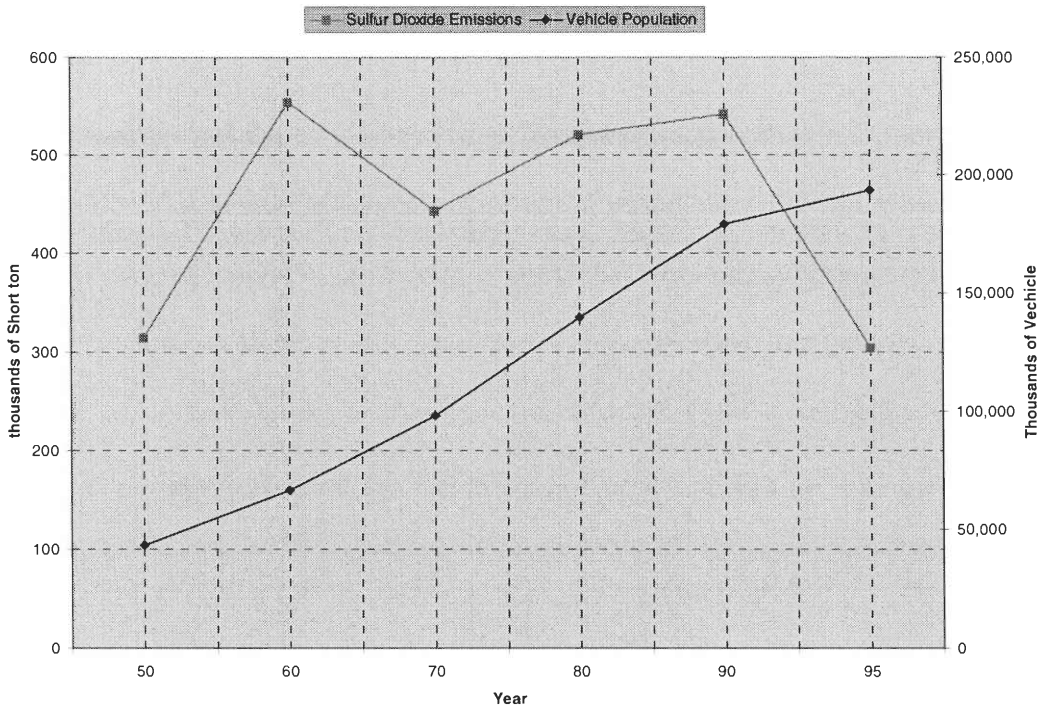
- 1981: New three-way catalysts with on-board computers and oxygen sensors appears in new cars and help them meet the Amended (1977) "Clean Air Act".
- 1983: Inspection and Maintenance (I/M) programs are set up throughout the country. This required motor vehicles to undergo emission control tests periodically to check for malfunctioning emission control systems.
- 1990: The "Clean Air Act" was amended by the Congress, there by requiring further reductions in the HC, CO and NO_x emissions.

5.4.3 Sulfur Dioxide

CO, Nox and VOC vehicle emissions are caused because of the partial burning of fuel in an internal-combustion engine. However, Sulfur Dioxide emissions are caused not because of partial burning of fuel but because of using fuels that contain sulfur impurities. Sulfur is not an additive to fuel, but an impurity found in crude oil. If the crude oil is not desulfurized, during refining then the resulting fuel product will retain the sulfur. Vehicles that consume diesel fuel have been mostly responsible for on-road SO_2 emissions. This due to the higher sulfur content in diesel. This is good example of air quality improvement brought out by improvements in fuel quality and not through the modifications to engines.

However, SO_2 emissions due to on-road vehicles only contribute to around 3 to 5 percent of total national SO_2 emissions. Hence, it was not until 1990 that the EPA looked at SO_2 emissions from on-road vehicles. In 1990, the EPA published regulations that govern the desulfurization of diesel motor fuel. This resulted in a dramatic drop in SO_2 emissions due to on-road vehicles within a short span of 6 years, as can be seen in figure 4-4. The below chart gives you an idea of how effective it was.

Figure 5-4 Total on road-vehicle SO_2 emissions 1950-96 [59][34]



Sulfur Dioxide Emission Reduction Milestones: [57]

- 1990: Limits imposed on diesel sulfur content by the U.S.E.P.A in order to help them meet the 1990's emission standards.

- 1993: Limits on sulfur content in diesel go into effect. California's rule kick in.

- 1994: Cleaner vehicle standards and technologies go into effect as required by the 1990 Clean Air Act.

Chapter 6 Curtailing Electricity Pollution

6.1 Economic Progress Vs Pollution Control

It is essential that we to understand our economic dependency upon technology. Technological adaptation whether it was adapting the internal combustion engine or the personal computer, has been a major driving force in our economic progress. However, in the long run we can not overlook the role that newer technologies play in polluting the ecosystem in the name of progress. It is hence vital to find a middle ground between economic progress and pollution control. The environmental movement of the sixties and seventies brought about a change in the way people think about economic progress and pollution. People then held the opinion that economic progress and pollution control could not go hand in hand. It was either one or the other. Through the pollution control initiatives taken up by the E.P.A, we found this was not true.

An important achievement of the environmental legislation was in finding a balance between economic progress and pollution control. The E.P.A has been successful by working with the industry in gradually reducing emissions over time. The E.P.A understood that they would not be able to bring about radical changes, such as replacing internal combustion engine. By understanding this fact and taking a gradual approach to curbing vehicle emissions, they met with success. Over time, they also succeeded in changing the attitudes of automobile manufactures too. We see this change in attitude every day as more and more automobile manufactures try to tout their pollution control efforts. This concept of having economic progress without causing serious damage to the ecosystem, is also known as "responsible progress".

Just as in the case of vehicle emissions and air pollution, the concept of responsible/sustainable progress is key to curtailing electrical power pollution. If we are to embark on a serious effort to curtail electrical power pollution, we must first understand the following:

1. In the effort to curtail pollution dependencies upon polluting technology should not be over looked.

2. To sustain future growth we must curtail pollution.

3. Pollution control is a long-term effort, we should not expect a radical change over-night.

6.1.1 The Growing Dependency Upon Electrical Energy

In 1970, electricity accounted for nearly 25% of U.S energy requirements and now accounts to more than 40%. Between the 1994 and 1998 the total electricity consumption in the U.S has increased by around 10% (Table 6-1). This increase in demand is not just due to a few customer categories as we can see the increase across all customer categories. According to a study published by the Energy and Power Research Institute (EPRI), by the year 2020 the electrical energy is going to account for around 50% of the energy consumed world-wide. At the same time electricity consumption will raise increase from around 13 trillion kWh to around 36 trillion kWh in 2020 (Table 6-2) [61]. These estimates are based upon an average Gross World Product (GWP) growth rate of 2%, over the next twenty years. Most of increase in generation capacity will be seen developing countries.

Table 6-1 U.S. Annual Electricity Consumption 1994-1998 [1]

Sales (million kWh)	1994	1995	1996	1997	1998
Residential	1,008,482	1,042,501	1,082,491,	1,075,767	1,127,735
Commercial	820,269	862,685	887,425	928,440	968,528
Industrial	1,007,981	1,012,693	1,030,356	1,032,653	1,040,038
U.S. Total	2,934,563	3,013,287	3,097,810	3,139,761	3,239,818

Table 6-2 Global Trends in Electrical Energy [2]

Year	1950	2000	2020	2050
World Population (billions)	2.5	6.2	8	10
Gross World Product ($trillions)	4.3	32	50	100
Electricity Fraction of Primary Energy (%)	20	38	50	70
Electricity Generation Capacity (thousands of gigawatts)	0.2	3	5	10
Electricity Consumption (trillion kWh)	1	13	36	60
Per Capita Electricity Consumption (kWh/yr)	400	2,100	3,500	6,000

To understand how dependent we are upon electronic technology we just have to look at the last two decade. Innovation in semiconductor technology has brought about the personnel computer and many more electronic devices. Other innovations such as fiber optics have revolutionized communications. The relationship between proliferation of electrical technology and our economy cannot be more evident than in the case of the Internet. The Internet came about as a merger of these two fields (computers and communication). As we can see from fig 6-1, the Internet is growing at an exponential rate.

The accelerated adaptation of technologies such as the Internet is playing an important factor in the economic growth seen in the last few years. For instance in 1996, there were 7.4 million people working in so called high-tech jobs, earning an average of $46,000 [63]. This is fifty percent more than the national average of $28,000. Since 1993, a quarter of all U.S economic growth is due to new technology industries such as information technology. The Internet economy alone has estimated to have grown from five billion

[1] Source U.S Department of Energy [62].

[2] Source Energy and Power Research Institute [61].

in 1995 to around 300 billion (Table 6-3) in 1999. Even the government has understood the importance electronic technology for future economic growth. The US Department of Commerce now has an e-commerce division, whose sole responsibility is to create laws that govern burgeoning amount of commerce on the Internet (table 6-3).

The global communication networks that server us in communication, trade and finance are all made possible because of electricity. The electronic technology and the Internet is leading to improved workforce productivity as noted by Alan Greenspans, Chairman of the U.S. Federal Reserve Bank, "The newest innovations, which we label information technologies, have begun to alter the manner in which we do business and create value, often in ways not readily foreseeable even five years ago [63]." These productivity gains are essential to offset the widening pension and health care deficits of the aging populations in the developed nations [64]. For developing nations, the knowledge-based economy that is being made possible by the Internet may help in accelerating their way out of poverty.

Figure 6-1 Computers on the Internet [1]

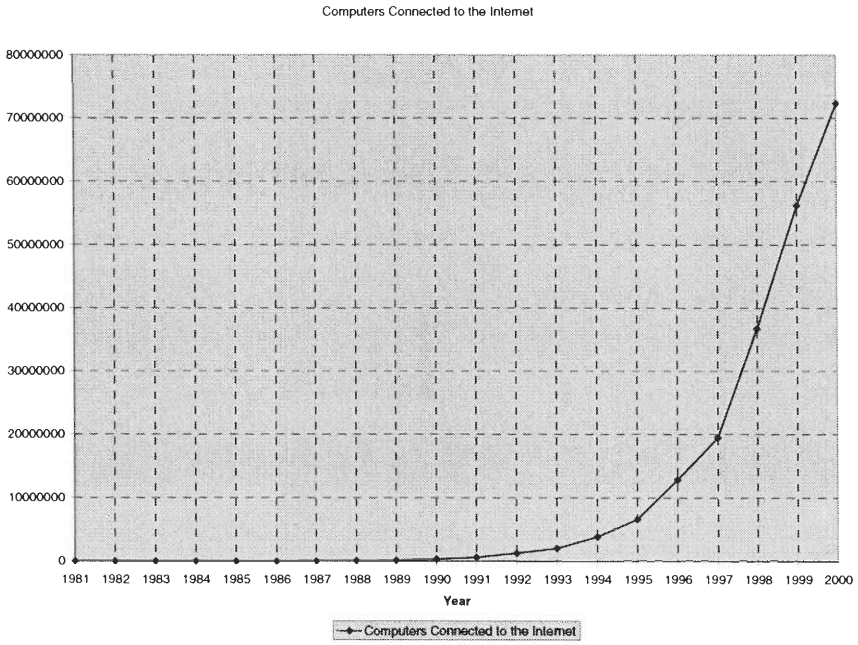


Table 6-3 Growth of Electronic Commerce

Year	1995	1996	1997	1998	1999
World Wide GDP in $billions [65]	33,646	35,714	37,870	39,103	40,714
US GDP in $billions [65]	6,762	6,995	7,270	7,552	7,798
Internet Economy in $billion [65]	5	-	-	-	301

[1] Source Internet Software Consortium [41]

However, the Internet it self relies on the electricity infrastructure to function. We must understand that in order for the benefits of an electronic future to be possible the electricity infrastructure must be much more reliable. Over the last few years, we have seen a rush towards adapting the newest technologies such as the Internet. However very little effort is being placed in preventing the damage to the electrical infrastructure from these new technologies. The rapid growth of the Internet increases the dangers of electrical pollution for the following reasons.

- Our reliance on computers is proliferating.
- Computers and other electronic devices are the sensitive to electrical pollution, and hence are the most effective.
- Effects of power pollution are much more far reaching due to the electronic communication media such as the Internet.

6.1.2 Sustainable growth of the electrical ecosystem

Between the 1940s and 1970, vehicle emissions increased in correspondence with the increase in vehicle population (fig 4-2 and fig 4-3). Automobile manufactures never thought about the long term effects of emissions as the vehicle population grew. When the first automobiles were manufactured pollution from them was negligible since there were so few of them. Hence until the 1970s, there was barely any money spent on developing technologies to make cars cleaner, and as a result of this pollution rose along with the vehicle population. When in the 1970s the governments decided to tackle the growing pollution. They understood that the polluting nature of the vehicles, increase in vehicle population. The government placed efforts on getting the automobile industry to designing cars that are less polluting. This applies to the electric power pollution too. The real problem is the polluting nature of the devices that make up the electrical ecosystem and not the usage of the devices.

If the talk about an electronic world is to become a reality, it is necessary that we find ways of sustaining the growth of the electrical ecosystem without damaging the infrastructure. If we do not start trying to curtail harmonic/electric pollution, it is bound to get much worse. In order to sustain the current growth of the electrical ecosystem, equipment manufacturers have to work along with the electricity providers and consumers to solve this problem. As we have seen in Chapter 2, electrical equipment (rectifiers, electric arc devices) is the major cause of harmonic/electric pollution. With our growing dependency on electrical equipment, it would impractical to stop harmonic/electric pollution by stopping consumers from using electrical equipment. Instead, it would be better if electrical equipment manufacturers can modify their products so that they reduce the amount of pollution they inject into the power stream (in other words reduce the distortion that they cause to the power stream). To do so equipment manufactures and electric companies (electricity service providers) have to agree on standards. This may require setting up of regulatory with a mandate to curtail harmonic/electric pollution. To succeed in curtailing power pollution such an organization would have to do the following.

- Create standards for limiting electric pollution levels.
- Enforce compliance to standards universally.
- Monitor power pollution.
- Taking action, against polluters.

- Toughening of harmonic/electric pollution emission standards over time.
- Fund research for curtailment of harmonic/electric pollution.

6.2 Curtailing Electricity Pollution

One of the key, problems facing the industry and courts now is that there are no proper laws that tackle harmonic/electric pollution. Since Electric power pollution is a well understood problem in the industrial and academic worlds, but unfortunately not in the political world. Government involvement is as necessary as was in curtailing vehicle pollution. One of the first tasks that faces the industry is to educate law makers on the problem of electric power pollution. The best way that the industry can achieve this is through increased lobbying.

6.2.1 Need to get Equipment Manufactures Involved

As we have seen in the previous sections the proliferation of new electrical equipment in increasing day by day. At the same time harmonic/electric pollution is increasing and resulting in degradation of power quality. Given the vast number of consumers that use electrical equipment, it is impractical to monitor each consumer and penalize them for harmonic/electric pollution. As with curtailing automobile emissions, here too "prevention is better than cure". The cause of the pollution is the device and not the usage of the device.

Till now harmonic/electric pollution and power quality problems that it causes were a major concern to the electric power industry. The lone efforts of electric industry will become more burdensome and will not be sufficient to meet future need. If we are to succeed in curtailing harmonic/electric pollution, We can get the polluting devices to reduce the amount of harmonic pollution. In order to do so we need to get electrical and electronic equipment manufacturers involved. The equipment manufacturers must understand they must work hand in hand with the electrical industry to tackle power pollution. As we have seen in chapter 2, most of equipment that is damaged due to harmonic/electric mostly consumer side equipment. Solving electric pollution is in every ones interests.

6.2.2 Anti-pollution Laws and Emission Standards

After the E.P.A was founded one it's first tasks, was to set pollution standards. Setting standards is the foundation of any pollution curtailment effort. We must also recognize the fact that setting limits and standards is an ongoing process. As we have seen in the previous chapter, the E.P.A had succeeded in curtailing automobile emissions toughening the limits on emissions, over time. By progressively reducing the standards for emission limits and getting the automobile manufactures to comply by them, they brought about a turn around in vehicle pollution.

As we have seen in chapter 2 in order to help electric utility companies curtail harmonic/electric pollution organizations such as the IEEE and the EPRI, have worked out standards such IEEE 519-1992. By doing so the initial frame work for curtailing electric/harmonic pollution has been laid. However, the biggest problem faced is in getting equipment manufacturers to abide by these standards. As we have said before till now electric pollution control has been an effort of only the electric industry. Both the electric industry and the electrical/electronic equipment industry are highly fragmented. This in has hindered electric pollution control efforts no one company or even a group of companies can get most the equipment manufacturers to comply. This has resulted in a lack of momentum in the electric pollution control efforts. The electric companies have nether the legal rights, nor the monetary means to do so. The founding of the E.P.A resulted in the bringing together of the various pollution control efforts. This in turn helped move forward the pollution control process. In order to push forward the electric pollution control effort a single body with the

legal authority and the monetary means to combat electric pollution has to be established. Getting the government involved in this is a necessity. The electric utility companies may have the ability to pool monetary and technical resources together to create such a body but they lack the legal authority to get equipment manufacturers to comply. If a regulatory body is created to oversee the electric pollution control effort it may take the form of one of the following.

- State Regulatory Body
- Federal Regulatory Body
- Self Regulatory Body

Which ever of the above it is, the involvement of the government is still a necessity. The government must understand that it is need for the following reason. Future economic growth will be heavily dependent on electric technology. Which in turn, is dependent on the stability of the electrical infrastructure. Hence, damage to Electricity infrastructure such as electrical must be curtailed. The consumers should not be penalized for using a polluting device. This is because even if a consumer is penalized for a using a specific type of device he will not stop using it, since he has no choice. Just as an automobile driver will not stop driving if he is taxed for driving. Given the vast number of devices used it will be hard, expensive and less effective to penalize consumers who are small polluters. The proper approach to tacking this problem would be to work with electrical and electronic manufactures in design devices that are less polluting. This idea of targeting the device instead of the usage can be effective in mitigating consumer side pollution, but some times the root of the problem may not just be the device.

6.2.3 Monitoring Electrical Pollution

One of the biggest ongoing tasks of the E.P.A is monitoring the effects of automobiles on air quality. This is a huge monitoring effort where the EPA works along with organizations such as the National Oceanographic and Atmospheric Administration (NOAA), Department of Transport, Department of Energy, Department of Commerce, National Environmental Data Index, etc. This monitoring effort results in a large amount of statistical data that provides the E.P.A with feed back on its vehicle emission control program of the office of Air. The work that the USEPA does in this regard is a very large undertaking. However, the rest of the curtailment effort is not useful if we do not know the results. In order for curtailment of harmonic/electric pollution to work, monitoring is essential. If a regulatory body is formed to combat electric pollution it will have to work with electric distribution companies. It may be necessary to collect data from conducting periodic tests on distribution lines. This monitoring effort should be undertaken on a long-term basis, this will give the regulatory body feedback on the effectiveness of the curtailment effort are, and in the short-term help catch polluters.

6.2.4 Funding Future Research

Until now, researchers in universities and industrial labs were working on harmonic/electric pollution and other power quality problems. Mostly of the funding for this had come from electric industry. This effort on their behalf has resulted in many new technologies that help solve harmonic/electric pollution and other power quality problems. It has also lead to a wealth of information that will help improve the robustness of the electricity infrastructure. Despite this the spending on research and development in the energy industry (electric and non-electric) lags significantly behind other industries (figure 6-1). A Report published by the EPRI states. "The U.S. significantly under-invests in energy technology R&D. This under-investment, in an area at the heart of the environmental-economic nexus, is detrimental for both long term U.S. energy security and for global environmental sustainability. In particular, since the U.S. path is intimately tied to

the evolution of global energy systems, this under-investment in energy technologies is likely to reduce the options available in the future to the global community to address the environmental impacts of energy production and green-house gas emissions. Ultimately, meeting the challenges will require increasing both U.S. and international energy technology R&D. [66]" Much of this is due to the government's neglect to fund long-term research in this area of science and technology.

Figure 6-2 R&D as % of Net Sales by Industry, 1995

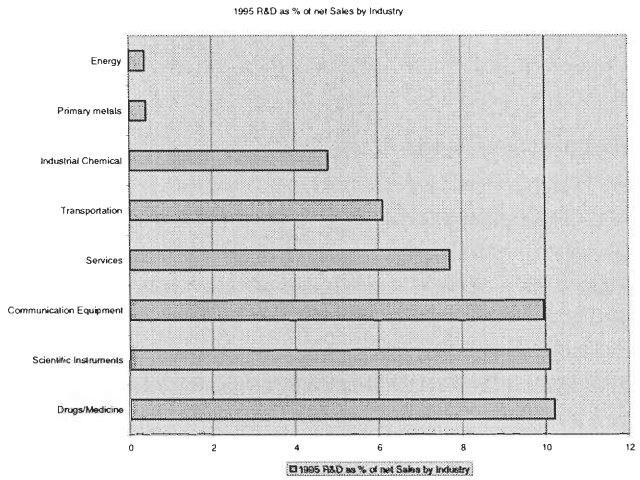
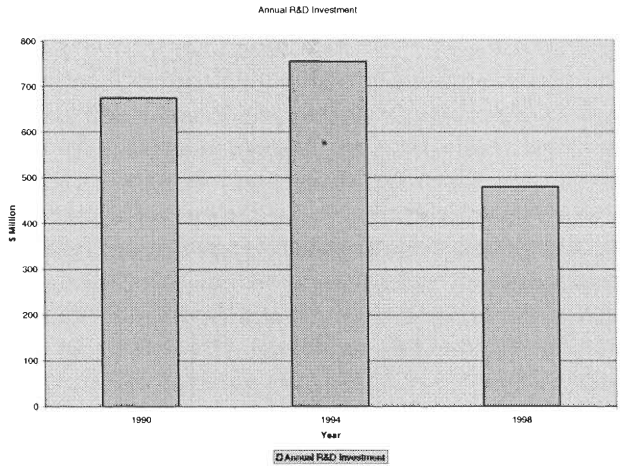


Figure 6-3 Annual Utility R&D Investment, $Millions [67]



Currently the U.S federal energy R&D funding is the lowest in 30 years. At the same time deregulation of the electric industry has resulted in competitive companies, which are unwilling to invest in long term R&D efforts such as harmonic pollution control [67]. This has lead to declining investments in the R&D in the 1990s (fig 6-2). The declining investment in R&D puts future R&D funding for electric pollution up in the air. We have seen that electrical pollution levels shall increase with increased proliferation of electrical/electronic technology over time. At the same time, we are become ever more dependent upon this new electronic world. If we do not increase R&D spending for electrical pollution control, a precarious

situation will develop. It is essential that the government increase the investing in long term Research efforts for the electrical infrastructure. It is also essential that they fund more R&D efforts in electric pollution.

6.3 The Need for a Government Involvement

Unlike many countries in the world, the U.S Government has always decided against getting directly involved with the operation of utility companies (Ownership of utility companies). That is why most utility companies in this country have never been under government ownership. In 1965, the great northeast blackout raised grave concerns about the way in which electric power supply was being managed. This along with the environmental movement of the 1970, which was also targeting the electric power industry started to question the ability of utility companies to solve the various scientific and technical problems that they were facing. In 1971, the U.S Senate tried to establish a federal agency with a mandate of conducting electricity-related research and development. Threatened with this prospect utility companies banded together and created the Energy and Power Research Institute (EPRI.). The EPRI is an independent research organization, which is collectively funded by the electric power industry. The EPRI works on some of the industries most pressing problems, one of them being power quality.

The EPRI serves as a good model of how self-regulation can be effective. However, there are issues that make it impractical for an organization, such as the EPRI involved in power pollution regulation. Despite the vast technical knowledge that the EPRI has in dealing with power pollution, the EPRI is a research institute and not a regulatory body. Till now harmonic pollution is a problem that in which only the electric industry was interested. In order to successfully curtail electricity pollution, measuring similar to those adopted by the E.P.A in curtailing vehicle pollution must be applied. Equipment manufacturers are bound to resist any such measure. Even if the manufactures join the electrical industry in setting up an independent organization, it will still be faced with enforcement issues. Given the vast number of electrical/electronic companies located throughout the world it will be hard for any self-regulated body to come to a consensus on decisions. Hence, a single federal agency would more effective than any organization that is setup by the industry itself.

6.3.1 State Vs Federal Involvement

There is a necessity for government involvement in the effort to curtail electrical pollution. However, would federal involvement be better than state level effort in curtailing electrical pollution, or vice-versa? To help us answer this question let us look at the vehicle emission control. Smog started to appear in cities and counties with high vehicle population such as Los Angeles. Hence, some of the earliest air-pollution control legislation came from local governments (municipalities) (fig 6-4). However, most of this effort was not successful. As we have seen in chapter 5 (fig 5-1,5-2,5-3,5-4), on-road vehicle emissions increased in trend with the increasing vehicle population until the 1970s. After 1970, the federal and state governments stepped up efforts to curtail vehicle emissions. Early effort by local authorities did not get vehicle manufacturers work on curtailing emissions. At the most, it succeeded in getting companies to crank out technical reports about automotive emissions.

Table 6-4 History of U.S Municipal, County and State Air Pollution Control Legislation

Year	1920	1930	1940	1950	1960	1970	1980
Municipal*	40	51	52	80	84	107	81
County*	1	2	3	2	17	81	142
State*	-	-	-	-	8	50	50

Smith Griswold the L.A county air pollution control officer, made the following comments at the 1957 National Advisory Committee to the U.S Surgeon General. "We have done everything that it is within our power to do", he said. "We have cleaned up industries that other section of the country have deemed impossible to control-steel mills, petroleum refineries, smelters, rail-roads, shipping. We have helped our electric utilities contain more gas for their steam plants. We have issued 5000 citations in the last three years, and levied half a million dollars in fines. Despite this, we still have smog." He went on to say, "There remains one source of air pollution beyond our power to control. Every day in Los Angeles County, 2,700,000 automobile are burning five and a half million gallons of gasoline, and fouling our air with 8,000 tons of contaminants. These emissions include: 6,400 tons of carbon monoxide, 300 tons of oxides of nitrogen and 1,050 tons of hydrocarbons [69]." From this, we can see that local administrative efforts to curtail vehicle pollution were not successful.

The main advantage of federal enforcement is that the more widespread the enforcement effort is the more effective it is. Power quality standards that are not uniform throughout the country will result in damage to the electrical infrastructure, lead to higher cost for transmission equipment and make it interstate trade riskier.

1. Federal regulatory bodies are more powerful since they represent the country as a whole. Since all products sold in the country by a certain manufacturer, they are more obliged to comply.

2. State level regulation will lead to fragmented policy. Manufacturers will need to meet different standards in different states.

3. Redundant efforts, will lead to too more work and costs on the part of the government.

4. More expensive for manufacturers. Extra costs incurred by manufacture will be passed on to consumer leading to higher costs.

5. Hard for each state to get the thousands of equipment manufacturers from all parts of the world to comply.

6. Energy suppliers and equipment manufactures in some cases may not be based in the state.

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* Number of Jurisdictions with Statutes [68]

6.3.2 Regulation in the age of deregulation

The federal government restricted its involvement in regulating electricity trade to the regulation of atomic energy usage (through the Department of energy), and inter-state power trade (through the FERC). On the other hand, state governments were more closely involved in regulating the industry. State level regulatory bodies were involved in the

1. Setting electricity rates, and deciding profits margins for utility companies.

2. Monitoring the quality of service provided.

3. Estimating Demand and controlling supply.

However as we have seen in chapter 3, a wave of deregulation swept the utility industry in 1990s. Deregulation of the industry brought about a changed in government involvement in the industries day to day activities. Given this shift in direction towards deregulation, the industry is now faced with the challenge of convincing the federal government to get involved in power pollution curtailment.

1. Only the government has the ability to create and enforce, standards and law.

2. Electric pollution involves consumers, equipment manufactures and electricity providers. A neutral non-biased organization is needed, in order to get them all to co-operate with efforts to control power pollution. Only the government can accomplish this.

3. Only the government has the means to fund long-term R&D efforts, such as power pollution control.

4. The increasing dependency on electricity is a reason for the government to get involved the long-term issues involving the electricity infrastructure.

However, as we have seen in the previous section successfully curtail electrical pollution government involvement is necessary. So, does this mean the creation of another EPA? The answer to this is no. The EPA was created in order to help the government tackle the many environmental pollution problems. Automobile emission control is only one of a large number of programs that the EPA addresses. Hence the EPA is very large agency with a big agenda. The government is already involved in energy business through the Department of Energy and the FERC. However over the years a trend towards a smaller government has arisen. Hence, federal involvement in the dead to day operation industry has decreased. Hence if the federal government it is to get involved in the effort to curtail electrical pollution the it should create an organization within an existing department such as the department of energy.

6.3.3 Enforcement of standards

Creating a federal agency that oversees the creation of standards and laws that control electrical pollution, will be an important step in curtailing power pollution. However, all this effort will useless if a process to test and certify compliance does not exist. Hence, the next goal would be to get the large number of equipment manufacturers to comply with emission control standards. A federal agency could be given the responsibility of overseeing enforcement effort. However, unlike the case of automobile emissions control in which the E.P.A had to work with a dozen or more manufacturers. In the case of electrical pollution, compliance enforcement must be done across, hundreds of manufacturers that manufacture millions of devices. This is irrespective of whether a manufacturer produces a few dozen electrical devices or a few thousand. All electrical equipment that draws power from an electrical distribution network should be tested for compliance to electrical pollution standards. It would be hard to create and operate a federal agency that

had the technical and financial ability to conduct all the testing required to verify compliance. Instead, alternate means must be used.

To understand how testing can be done in a cost-effective manner, let us look at the electromagnetic interference (EMI) certification process overseen by the Federal Communication Committee is done. One of the jobs of the Federal Communication Committee is to regulate the usage of the Electromagnetic Spectrum within the United States. The Electromagnetic spectrum also known as the radio spectrum is the continuous range of frequencies in that electromagnetic signals such radio, television and satellite signals use. The radio spectrum is a limited resource. Given the importance of the radio spectrum and the potential for interference between different users, the government took the responsibility of regulating the usage of it. One of the responsibilities entrusted to the FCC is radio frequency licensing. The FCC allocates frequency bands for various commercial, military and scientific purposes. This prevents various users/signals from interfering with each other, in other words it prevents electromagnetic interference. . It then grants licenses to users in a manner so that they do not interfere with each other.

However, sometimes electrical and electronic devices may unintentionally emit radio emissions in a frequency that has been previously allocated to a specific purpose. This pollution is more commonly referred to as EMI. In order to prevent electrical devices from unintentionally causing EMI, the FCC requires that equipment manufacturers design their equipment to prevent causing EMI. Before selling the product, it must be certified by the FCC to meet specific emission limits. This is why most electrical and electronic devices have electromagnetic shielding.

However the FCC itself no longer tests equipment nor does it issue the certification. In May 1996, the FCC streamlined equipment authorization requirements for personal computers and peripheral devices. The new rules removes equipment certification requirements from the FCC Grant to a new self-authorization process based on the manufacturer's or supplier's Declaration of Conformity (DOC) to limiting radio frequency (RF) emissions in personal computers and peripheral devices. Prior to this manufacturers were required to submit written applications and test report and fee for equipment authorization for FCC approval. This process was centralized labor intensive and would take several months to complete. The changes align the FCC equipment authorization requirements for computers with those used in other world markets. This resulted in the current decentralized system.

According to the new FCC "Declaration of Conformance" method. In order to self-declare for the DOC, the FCC requires that EMI testing be conducted by laboratories accredited by the National Institute of Standards and Technology (NIST) through the National Laboratory Accreditation or other programs approved by the FCC [70]. In some case industrial testing labs such as UL have been certified to conduct testing to the EMI requirements of the U.S. Federal Communications Commission (FCC) through the National Voluntary Laboratory Accreditation Program (NVLAP). A complete list of testing firms can be accessed over the worldwide web from the FCC database (http://www.fcc.gov/oet/info/database/testsite/). By aleaving itself of the responsibility of conducting the actual testing and certification, the FCC's responsibility has been reduced to monitoring certification lab, instead of each device manufactured. Similar methods can be adopted to enforcing harmonic emission standards upon equipment manufacturers. By doing so, the role of the federal agency can be more effective.

Chapter 7 Conclusions

The rapid innovation along with the increased adaptation of new electrical technology is leading to proliferation of electrical technology. The proliferation of this new electrical technology is changing the electrical landscape. This proliferation of electrical technology is economically beneficial since leading to higher productivity. However, some of the equipment proliferating posses non-linear load characteristics. Nonlinear loads are known to be the primary cause of harmonic pollution. This new form of pollution is becoming a growing menace, since it leads to the degradation of power quality. Harmonic pollution have the tendency to permeate the electrical infrastructure and damage a wide variety of equipment especially affecting sensitive electronics such as computer systems. Hence, the very proliferation of technology that we are benefiting from is also polluting the electrical ecosystem.

If electrical pollution is not curtailed will result in heavier damages. The real extent of damage due to electrical pollution will be much higher in the future. The more devices that are connect the farther the disturbance. This is where new electronic technologies such as the Internet create a ripple effect. If left unchecked electrical pollution will potentially lead to dangerous breakdowns in the electrical/electronic infrastructure in the future. Curtailing electrical pollution is important if the current growth of the electrical ecosystem is to be sustained. Until now, electric utility companies have taken an interest in curtailing electrical pollution. However, with the de-regulation of the electric industry, ownership of the electrical infrastructure is becoming increasingly fragmented and companies are becoming more competitive. This is leading to a situation where companies are unwilling to take up the increased burden of curtailing electrical pollution. In addition to this, the current product liability laws are not useful in preventing electrical pollution from occurring.

Inorder to successful curtail power pollution, we must rethink the current approach taken to curtail electrical pollution. Electrical pollution is a pollution problem, just as automobile emissions is a pollution problem. Hence, it should be tackled as a pollution problem. The first step is to identify the cause. The users of polluting equipment are not the cause, but the manufacturers of such equipment are. The next step would be to get manufacturers to reduce emissions. However, as we have seen in case of automobile emissions this is a daunting task. Neither utility companies nor do consumers have the resources and power necessary to convince equipment manufactures to comply with standards. In order to do so, government involvement is necessary. As we have seen in the case of automobile emissions, the government played an important role in curtailing emissions, by making automakers abide by emissions standards. Only the government has the means of stopping equipment manufacturers from producing polluting devices. To do so we will need new electrical pollution control laws. This can be accomplished by creating a federal agency with a mandate to curtail electrical pollution and improving the quality of electrical pollution. So an agency would have the ability to enforce laws across the country. If such measures are taken, then it will succeed in breaking the relationship between technology proliferation and pollution. This will lead to sustainable growth of the electricity infrastructure well into the future.

Index

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