

THE ELECTROMAGNETIC INTERFERENCE AND THE COMPUTER NETWORKS

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Abstract: *The electromagnetic interference (EMI) between different devices in critical and non-critical environments (as household devices, industrial environments and especially for the medical sector) is one of the new challenges arising for design engineer, following the wide spread of advanced electronic systems and solutions. This phenomenon can compromise the operation of the computer devices. The main objective of this paper is to present the negative effects of electromagnetic disturbances from the power grids on the computer networks, as well as to briefly illustrate the necessity and advantages of using EMI filters to solve the problems related to the electromagnetic interference.*

Keywords: *Electromagnetic Interference, Electromagnetic Disturbances, Computer Networks, Power Grids, Filters.*

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INTRODUCTION

The increase in the complexity of technology often results in an increased sensitivity to various disturbances, an aspect encountered in all areas related to Information Technology. In fact, before everyone's eyes, there is a dizzying increase in the miniaturization and complexity of integrated circuits, such as those used for PCs. The number of transistors contained in the chips that make up processors has always grown exponentially, doubling roughly every 18-24 months ("Moore's Law"). One of the first Intel chips, the 4004, developed in 1971, consisted of 2300 transistors and processed 92,600 instructions per second. A 2008 Quad-Core 45-nanometer Core 2 processor has 456 million transistors and processes billions of instructions per second (Intel does not provide figures for this). Moore himself, a co-founder of Intel, predicted for 2011 chips composed of a billion transistors capable of 100 billion instructions per second. Inevitably, in today's market conditions, the increased complexity has not led to a greater reliability. In the case of the personal computer, inexplicable crashes of the operating system are no less common than in the past. A study carried out by IBM concludes that 80% of damage to computer systems is ultimately due to failures in the electrical power supply.[1]

In the meantime, the growth of smart cities, with their interconnected networks of sensors and devices, presents new challenges in managing electromagnetic interference. The growing reliance on wireless communication and data transfer requires robust solutions to ensure uninterrupted connectivity. The rise of autonomous vehicles introduces further complexity, as these systems rely heavily on precise electronics and communication systems that must be resistant to interference. Furthermore, the expansion of renewable energy sources (RES), such as solar panels and wind turbines, contributes to the electromagnetic environment, requiring careful consideration of their impact on surrounding electronics and power supplies. [2]

The continued miniaturization of electronic components also increases their vulnerability to interference, requiring innovative protection strategies. As these trends evolve, the need for comprehensive research (as we desire to be also this one) and development in the field of electromagnetic compatibility remains vital.

METHODOLOGY

Regarding the research methodology used, we have to mention that this paper is a descriptive one, the main information being taken from the acts and directives issued by the European Union institutions and from the United Nations and Romanian Government official websites.

In the mean time, we have to say that the idea of this paper was inspired during a meeting organized by the Romanian Ministry of Internal Affairs regarding the cyber security in the public administration institutions. Starting

from this point, we have studied various articles regarding this theme, published by the main actors in the field, with the aim to discover the causes of EMI and how to reduce its effects on the PCs and computer networks.

The paper is structured in five chapters approaching the phenomenon of the electromagnetic disturbances on the power grids, the effects of electromagnetic disturbance on IT equipment and PC networks and how to mitigate the effects of EMI.

THE ELECTROMAGNETIC DISTURBANCES IN THE POWER GRIDS

Until now there is no univocal classification and there is not even a complete agreement on the definitions and durations of the various disturbances. We present, next, three definitions, according to the Decision of the Romanian Government no. 487/2016 [2] on electromagnetic compatibility, which transposes the European Union Directive 2014/30/EU (EMC Directive) [3] into Romanian legislation:

- **electromagnetic disturbance** – any electromagnetic phenomenon which may degrade the performance of equipment; such as, but not limited to, electromagnetic noise, an unwanted signal or a change in the propagation medium itself; an electromagnetic disturbance may be electromagnetic noise, an unwanted signal or a change in the propagation medium itself;
- **electromagnetic compatibility** – the ability of the equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment in that environment. [4]
- **electromagnetic immunity** – the ability of equipment to perform as intended without degradation in the presence of an electromagnetic disturbance.

In this context, it should be mentioned that electrical and electronic devices use circuits that operate at high frequency (usually to maintain high efficiency and to reduce dimensions), thus generating high-frequency electrical signals that propagate through cables or through power lines. This phenomenon is also an "electromagnetic disturbance" (known, in English, as an Electromagnetic Interference – EMI). (see Fig. 1)



Figure 1: A Disturbing Electromagnetic Field (source: CONSYSTEM)



Figure 2: EMI Natural Sources (source: NEWHEAVEN DISPLAY)

Therefore, we can say that *any electromagnetic interference between two electromagnetic systems (such as that one between two electrical or electronic devices or that one between the electrical network and a certain electrical or electronic device) leads to an electromagnetic disturbance.*

In short, electromagnetic waves that propagate through air or vacuum, similar to how light travels from the Sun to Earth, are called **radiated disturbances**. (see Fig. 2)

On the other hand, disturbances that travel along cables and power lines are **conducted disturbances**. (see Fig. 3)

Generally, we can classify the electromagnetic disturbances in electrical grids into **semi-persistent disturbances** and **transient disturbances** (lasting less than half a second).

3.1. Semi-persistent Electromagnetic Disturbances

Current interruptions (voltage drops or current "feathers"), voltage fluctuations, frequency fluctuations, harmonic distortions of the waveform and voltage dissymmetry (in a three-phase system) are called **semi-persistent disturbances**. [4]

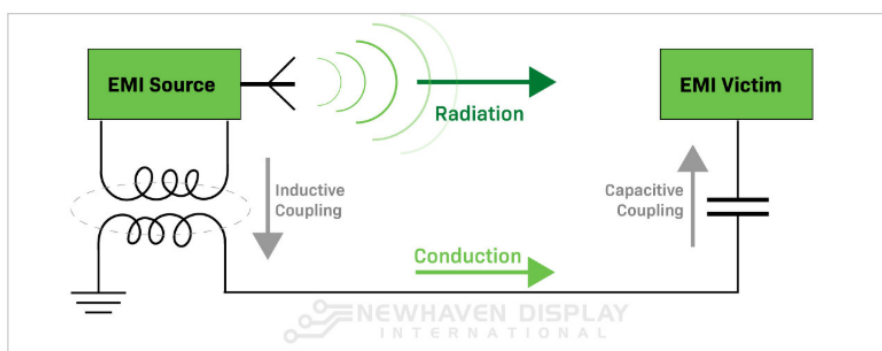


Figure 3: The Propagation of Electromagnetic Disturbances (source:NEWHAVEN DISPLAY)

3.1.1. Interruption of Electricity Supply (Power Cuts)

It refers to those faults in the electrical network when the voltage disappears for periods greater than one second. They generally depend on faults in the distribution network (excessive demand for electricity, storms, tripping on power lines), or when the protections of the user's system are activated, usually due to a short circuit.

Among the interruptions we must also include "forced deactivation", in other words, those due to the protection devices of the powered equipment when the voltage exceeds the preset limit values, especially the programmed interruptions.

3.1.2. Voltage Variations (overvoltages and undervoltages)

We talk about voltage variations (or fluctuations) when we are dealing with variations greater than 10% of the nominal value. They depend on the variations in electricity demand. Anyone has seen that the light goes out when a hot plate is connected to the power grid. This happens because, if the system is undersized (conductors of small cross-section), the insertion of new consumers causes a noticeable voltage drop along the cables themselves. Something similar can also occur in a company's network or, on a larger scale, at the level of an electrical substation that feeds several users. In practice, voltage fluctuations are quite frequent (more often than once a month).

3.1.3. Frequency Variations

The problem of frequency fluctuations arises especially in the case of the integration of photovoltaic systems into the classic electrical network. [5] The imbalance between solar energy production and energy demand is an essential problem in the energy sector. This phenomenon occurs when the power generated by the photovoltaic panels does not correspond to the energy demand of the consumers at a certain time of the day: the production of solar energy can vary significantly, depending on the weather conditions, the time of day or the season, which can lead to frequency fluctuations in the electrical network. These fluctuations can cause partial or total loss of electricity supply, thus affecting the efficiency and reliability of the network. Photovoltaic systems, which convert sunlight into electricity, are dependent on weather conditions and the time of day, in other words, solar energy is intermittent, that is, it is an irregular energy source, with maximum production during the day and zero at night. This characteristic makes it

difficult to ensure a constant and predictable supply of energy. In addition, photovoltaic systems are susceptible to various failures that can significantly affect the production of electricity. Failures can occur at every component of the PV system - from the solar panels to the inverter - and can be caused by a number of factors, including environmental conditions, design and installation errors, and normal wear and tear.

A very important aspect that must be emphasized is that solar panels and the traditional electrical network are based on different design principles. Centralized energy generation, i.e. the traditional model of the electrical network, involves the production of energy in one place, from where it is then transmitted to consumers. This model allows economies of scale, is more reliable and offers greater control over energy production. However, this model involves higher risks of interruption and significant energy losses during transport.

On the other hand, distributed generation, the model on which solar power is based, involves producing power at or near where it will be used. This model reduces losses, allows more efficient use of resources and offers greater flexibility. While the energy produced by the solar panels can be injected into the electricity grid to support clean energy production and reliable delivery, the current grid configuration requires some improvements for the two distribution infrastructures to work together smoothly. To compensate for the intermittent nature of solar energy, it is necessary to develop and implement efficient energy storage solutions.

These may include batteries for solar panels, thermal energy storage or other emerging technologies. By storing the surplus energy produced at peak times, these technologies enable the supply of energy during periods of low production, thus helping to balance the demand and supply of energy.

3.1.4. Harmonic Distortions of the Supply Voltage Waveform

Harmonic distortions (see Fig. 4) are the most frequent disturbances (in some cases, approximately once a day). By "distortion" is meant the deviation of the voltage or current waveform from the ideal (sinusoidal) form. This deviation is expressed quantitatively by the "degree of distortion". The lifetime of electrical equipment and apparatus depends a lot on the quality of the electricity, characterized by this degree of distortion. Waveform distortions are due to power absorption that is not proportional to voltage (non-linear load). All modern power supplies, for example, draw current only at times when the voltage reaches its peak value. Linear loads, on the other hand, draw current in a manner proportional to the voltage, i.e. in a sinusoidal manner.

Powering electronic devices requires a continuous voltage source. Depending on the energy conversion method, power sources are of two types: *linear sources* and *switching sources*. *Linear power supplies* are the traditional power supplies, consisting of a transformer that lowers the voltage to the module's needs, a rectifier that transforms the alternating voltage into direct voltage, a filter and a voltage stabilizer. *Non-linear power supplies* are the switching voltage sources present in all electronic devices and equipment today. In the case of a switching source, the alternating voltage is applied to a rectifier module that transforms it into direct voltage that supplies the switching element (transistors, thyristors), controlled in pulses by the control block.

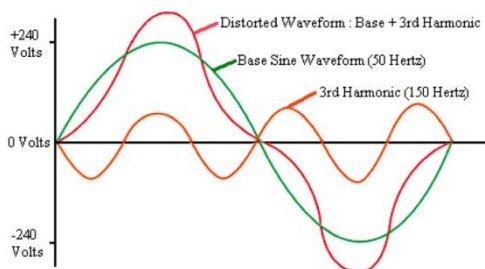


Figure. 4: Distortions of the Supply Voltage Waveform (source: CONSYSTEM)

This pulsed voltage is then applied to a load accumulator circuit which, after filtering, forms the source voltage. Due to the very high frequencies at which the switching element works, the voltage resulting in pulses is a voltage with a significant content of harmonics. These harmonics propagate in the power supply network, disrupting the proper functioning of other equipment. The presence of harmonics determines the increase (sharpening) or decrease (flattening) of the amplitude of the sinusoidal regime of the voltage of the supply network.

Most electrical equipment can function properly with a harmonic distortion (waveform distortion) value below a certain level. The greater the distortion of the parameters of the electrical supply network (voltage, current), the more efficient the supply system, but also the load (consumption) it can bear, decreases. Another negative effect is related to the unnatural heating of the cables, leading to their additional heating with one of the most destructive effects on the

electrical installation as a whole. If the user's electrical system is not sized very generously, the connection is reflected in the form of voltage fluctuations. So, if switching occurs impulsively, even the mains voltage undergoes distortions. The presence of harmonics causes malfunctions of electric motors, overheating of transformers, degradation of electrical insulations, but above all, it can cause errors in computer systems.

3.1.5. Dissymmetry of Electrical Voltages in a Three-Phase System

The causes that produce the imbalance of the three-phase system can be:

- **temporary** - in general, they appear due to the influence of faults on the network, which can occur between two or more conductors with or without grounding; these defects cause the appearance of voltage and current variations, different on the three phases and disappear with the defect;
- **permanent** - the phase imbalance is caused by causes of a constructive nature (power lines are not perfectly symmetrical geometrically or in low-voltage networks, some users are single-phase and are fed from three-phase networks, etc.). [6]

The spread of zero-sequence (homo-polar) systems is limited by delta-connected transformers. The propagation of negative sequence voltages (reverse) from a lower voltage network to a higher voltage one is strongly attenuated depending on the short circuit power of the high voltage system, while the propagation from one network to another lower voltage it is done with an attenuation that depends on the presence of three-phase rotating machines, which have a strong rebalancing effect. The symmetrization of electric currents has as its main effect the decrease of technical losses in the electric networks of both users and SEs.

A three-phase power grid, composed of lines, generators and receivers, can be represented in an equivalent scheme by the respective impedances. [7] If the impedances on the three phases of the grid are identical, that means they have the same module and the same argument, the power grid is called "balanced". If at least one of the complex impedances differs from the others, the respective grid becomes "unbalanced". In a balanced three-phase system, fed with a symmetrical voltage system, the electric currents that arise in the various elements, as well as the corresponding voltage drops, form *symmetrical three-phase systems*. With the exception of the three-phase short circuit, the other types of faults between the network conductors, with and without connection to the ground, lead to *asymmetric transient voltage variations* in the network, more or less pronounced. [8] The type of asymmetry or imbalance in the network can be represented by an interconnection between equivalent networks of different sequences. The imbalance of impedances, caused by some causes of a constructive nature or the imbalance caused by the uneven distribution of the load on the three phases of the supply network, leads to the appearance of permanent non-symmetric regimes, which are characterized by the appearance of negative/zero sequence components of the voltages and of electric currents in the respective power grid. [9]

Generally, from a constructive point of view, high voltage overhead power lines are not "balanced". In the case of arranging the three conductors of a circuit after the vertices of an equilateral triangle, an additional elevation of the support poles and a repeated transposition of the conductors is necessary to symmetrize these circuits, which sometimes cannot be completely achieved. Even under these conditions, an impedance imbalance results. In the case of the horizontal arrangement of the three conductors, the central conductor presents - at positive/negative sequence electric currents - a lower impedance by 6-10% compared to that of the other conductors. In this situation, the voltage drop is lower, which causes a slight unbalance at the user terminals. The imbalance of the load can be caused, for example, by receivers with non-symmetric construction which, connected to three-phase networks, absorb different electric currents on the three phases. This situation leads to an asymmetry of the voltage system. [10]

The probability of an imbalance on the three phases is higher in the case of networks with single-phase or two-phase users (electric traction, welding, single-phase or two-phase electro-thermal installations, household appliances, etc.). At the same time, in rural areas and even in peripheral urban areas, the supply for reduced and dispersed loads causes a power transit through the power lines much lower than their capacity. In these conditions, the concerns of reducing investment expenses led to the emergence and development of the so-called mixed three-phase-single-phase distribution system (such systems are found in North America - the mixed system with distributed neutral with neutral conductor - and in Australia - Mixed system without neutral conductor). This way of realizing the distribution system can induce important asymmetries of the electrical quantities in the three-phase power supply system. [11] Depending on the structure of the defect that leads to asymmetry, they can be [12]:

- longitudinal asymmetries, arising as a result of the interruption of a phase;
- transverse asymmetries, resulting from short circuits between phases or phase-earth;
- simple or multiple asymmetries, depending on the number of impedances or admittances that intervene;
- asymmetries, caused by zero and negative sequence components.

3.2. Transient Electromagnetic Disturbances

Short interruptions with fast recovery (or micro-interruptions), voltage pulses and high-frequency disturbances fall into this category of disturbances.

3.2.1. Micro-interruptions

They are mains voltage drops with an amplitude of 90% of the nominal value down to 0 Volts, with a duration between 10 milliseconds and 500 milliseconds. They come from the most varied transient phenomena, such as the automatic rapid opening and closing of switches on high-voltage networks (380,000 V). Other common causes can be short circuits in the network upstream of the user, before the intervention of the protection devices. They can be particularly harmful to computers because they are "read" as noise signals.

3.2.2. Voltage Pulses

They are transient variations in the mains voltage. They last from a microsecond to 500 milliseconds. The amplitude can reach over 800 V. The most common causes are automatic mains switching operations or sudden disconnection of inductive loads such as large electric motors.

A less frequent cause, but with disastrous effects, is lightning striking overhead distribution lines. Voltage surges can damage some types of electronic circuits, such as computer memories.

3.2.3. High Frequency Disturbances (Noise)

Disturbances are very common, especially in industrial areas. They have several causes: for example, the brushes of an asynchronous motor (in elevators) or the arc from an electric weld.

Other causes may arise from electromagnetic interference with high power radio transmitters, induction on overhead lines due to a lightning strike nearby.

A cause that should not be underestimated can be represented by even office equipment and apparatus, including low-quality UPS (UPS - Uninterruptible Power Supply, i.e. uninterruptible power supply; it is a power source that is found between the power network and household receivers when the network "fails" and has the role of protecting, at the same time, household consumers from possible variations in the supply voltage).

THE EFFECTS OF ELECTROMAGNETIC DISTURBANCE ON IT EQUIPMENT AND PC NETWORKS

Many unpredictable PC behaviors, such as operating system crashes, are common due to disturbances that can occur either directly due to anomalies in the operation of the electrical network, or can originate from ordinary, electrical devices connected to the network, such as . it would be, for example, a hair dryer in the home environment or electric arc welding in a factory. Overall, good quality power grids experience disruptions on average almost twice a week. In the case of a PC running on average one-third of the time (8 hours out of 24), a potential critical situation can be expected approximately every 15 days.

4.1. Effects on Hardware System

The effects on the hardware system are mostly related to the structure of the microcircuits themselves. Each of the millions of transistors they are made of has the structure of a microscopic capacitor, with the dielectric layer unimaginably thin. Over-voltages of several tens of volts are enough to perforate them. These components are so sensitive that manufacturers warn of the dangers of simply touching them, due to the static electrical charges that could have accumulated in the operator's body.

Larger over-voltages, which are transmitted through the network, can be responsible for burning microcircuit tracks, or even printed circuit tracks and its elements.

Among peripherals, magnetic disks are particularly sensitive. The distance between the read/write head and the disk surface is so small that a particle of cigarette smoke has an effect comparable to that of a boulder. The read/write head remains elevated by the layer of air that the spinning disk drags with it. Cheaper types of drives can experience voltage drops through a sudden head crash ("crash") resulting in total data loss.

Other damages may be much less obvious. A slight under-voltage can be easily compensated by a computer's power supply ("switching power supply") which absorbs a higher current. However, the competitiveness of prices on the IT market does not allow products to be oversized. This "over-exertion" results in earlier aging and a higher frequency of breakdowns. Over-voltages can cause damage similar to those in other types of circuits.

4.2. Effects on Software System

Software failures depend on the fact that any type of electromagnetic disturbance can cause an error in the interpretation of the data passing inside the circuits. The memories, especially, both the magnetic type and the MOS type, are very exposed to this risk. It is also true that there are protection algorithms in this sense, based on the addition of special codes that allow the detection of the error on one or more bits and even its correction. On the other hand, these methods can only correct one-bit errors (on current computers) and involve additional costs. These errors are reflected in malfunctions of the operating system (the "intelligence" of the computer) and in the application programs.

One of the most frequent sources of errors is related to the fact that the operating system reads and keeps in the central memory (MOS type) the tables of the file system and the data accessed more frequently ("buffering"). To speed up operations, changes are written to main memory instead of disk (main memory is about 100,000 times faster). Only occasionally, preferably during downtime, are these changes copied to disk. Power failures cause immediate wipe of main memory, with the possibility of losing data or entire files.

The causes and symptoms of anomalies in electricity transmission and distribution systems are complex, but the consequences for users are always the same: lost work, blockages in production processes and damage to expensive equipment. Even a shorter anomaly can have unacceptably high costs. In an analysis of various industries, at Westinghouse, a micro-disruption of about a tenth of a second was found to cost a glass factory \$200,000, and an outage of just over five minutes cost a semiconductor factory \$500,000. It is estimated that, in the United States of America, these losses amount to 3 – 5 billion dollars per year.

4.2. Effects on the PC Networks

Electromagnetic interference (EMI) can cause signal degradation, data corruption, and malfunctions in PC networks, resulting in decreased performance and potential connection loss. Interference is an unwanted "noise" that distorts electrical signals traveling through network cables (especially Ethernet), causing data communication errors.

4.2.1. Signal Degradation

The most immediate effect of EMI on PC networks (as RJ45 Ethernet) is signal degradation. Ethernet cables, typically made of copper wire, are susceptible to electromagnetic noise. This noise can distort the original electrical signals representing data bits. For example, in a Gigabit Ethernet network, data is transmitted at very high speeds, and even a small amount of interference can cause bit errors. When a bit error occurs, the receiving device may not be able to accurately interpret the data, leading to data loss or corruption.

4.2.2. Reduced Bandwidth

EMI can also lead to a reduction in available bandwidth. As interference increases, the network may need to spend more time retransmitting corrupted data packets. This retransmission process consumes valuable network resources, effectively reducing the amount of data that can be transferred within a given timeframe. For example, in a business environment where high-speed data transfer is crucial for operations like video conferencing and sharing large files, reduced bandwidth due to EMI can severely hinder productivity.

THE USE OF EMI FILTERS

Electromagnetic disturbances are a common problem for design engineers, as electronic devices must comply with the provisions of design standards. In addition, these electromagnetic interferences can also cause malfunctions in other devices, impairing their correct operation. They can come from various sources, internal or external to the device, of natural origin - such as electrostatic effects, lightning and solar flares, or of human origin such as signals from cell phones, radio signals and transport systems.

All these potential sources of electromagnetic interference cause problems in the operation of electronic devices, which is why EMI filters become necessary for the electrical and electronic industry. [13]

5.1. The principle of operation of EMI filters

EMI filters, also called “EMI suppression filters”, reduce electromagnetic noise by suppressing unwanted high frequencies. They are used to remove conducted electromagnetic disturbances. Positioned on the power supply at the entrance to the device, these filters prevent such disturbances from entering and causing malfunctions. In addition, EMI filters prevent the noise generated by the functional device from disrupting the power supply network and then interfering with other devices.

Basically, in the operation of an electromagnetic interference filter, we can identify three phases:

1. the source of a signal is connected to the input of the EMI filter;
2. the signal passes through the filter circuit, which cleans it of unwanted noise;
3. the conditioned signal reaches the output of the EMI filter.

EMI filters, in addition to blocking the introduction of high-frequency noise into the network, also help to avoid the consequences that voltage drops have on electronic equipment.

5.2. The Main Elements for Choosing the Right EMI Filter

Selecting the right filter for your application takes into account the choice of appropriate dimensions, its performance and cost. Different types of filters provide different levels of suppression and therefore have their own characteristics that differentiate them. A filter that works correctly in one system may not be effective in another. For this reason, it is necessary to select the right filter from the right supplier, through the many options present, dedicated to the specific typology of each application.

5.3. Types of EMI Filters

There are an infinite number of EMI filter models, each with different sizes, designs and configurations. To begin with, we can distinguish two main categories of EMI filters: **active** EMI filters and **passive** EMI filters.

5.3.1. Passive EMI Filters

They reduce emissions from a power circuit through a combination of passive and reactive components, such as capacitors and inductors, configured to attenuate specific interfering frequencies. Thus, they suppress current harmonics and reduce voltage distortions in sensitive elements of electronic devices. In this context, capacitors provide a low-impedance path for disturbing frequencies, redirecting them to ground or between power lines, and thus preventing them from propagating along the power line or to other devices.

5.3.2. Active EMI Filters

They are a perfect alternative to passive filters, which are very expensive and bulky. In active EMI filters there is a current generator and active circuits. In active mode, noise in the input signal is detected, and an appropriate cancellation signal (icancel) is introduced, which reduces EMI. The main advantage of this type of filter is its versatility, [13] which helps electronic device design engineers to reduce size, cost and optimize performance.

5.3.3. Single-phase filters

They limit the amplitude of disturbing voltages on AC lines and prevent them from spreading, and are commonly used in home and office equipment.

5.3.4. Three-phase filters

They are used in high-load industrial contexts and are designed to block higher levels of conducted electromagnetic interference, with a frequency range of 47 Hz to 400 Hz.

CONCLUSIONS

Preparing for future challenges related to electromagnetic interference requires proactive strategies and continuous adaptation. Industries must focus on research and innovation, investing in advanced materials, design techniques, and simulation tools that improve electromagnetic compatibility. One such development is the use of meta-materials, engineered to have properties not found in naturally occurring materials. These can effectively block or redirect electromagnetic waves, offering advanced shielding capabilities. Additionally, adaptive filtering technologies are being developed. The integration of artificial intelligence in the monitoring and management of electromagnetic environments is another promising area. Collaboration between academia, industry, and regulatory bodies is essential to foster an environment of knowledge sharing and problem-solving. Education and awareness are also crucial, as they enable consumers and manufacturers to make informed decisions about electromagnetic safety. Educating engineers and designers on the principles of electromagnetic interference and its mitigation, by developing predictive models and monitoring systems can help identify potential interference issues before they escalate. This forward-thinking approach will allow us to reap the benefits of technological advances while effectively managing the associated risks.

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