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Harmonic Sources In Power System-A Review

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ABSTRACT
Power utility companies worldwide prioritize maintaining power supply quality, with harmonic distortion being a key issue. Harmonic distortion arises from non-linear customer loads, background harmonics from utilities, and renewable energy sources. These distortions create current and voltage waveforms containing frequency components, known as power system harmonics, which are multiples of the fundamental frequency (50 or 60 Hz). These harmonics can degrade power quality, leading to insulation failures, overheating, increased costs, signal interference, and equipment stress. The growing use of power electronic devices, such as rectifiers, inverters, and cyclo-converters in battery charging systems, renewable energy, and electronics, contributes to harmonic generation. Moreover, electric furnaces, light emitting diode lights, electric vehicles, transformers, and variable frequency drives are major harmonic sources. These distortions impact the performance of the grid and plant distribution networks, making their study crucial. This article offers an in-depth analysis of various harmonic-producing sources.

Keywords:-Three phase Transformers, Variable Frequency Drives, Electric vehicle, Uninterruptable Power Supply, Switch Mode Power Supplies, Light Emitting Diode, High Voltage Direct Current, etc.

1. INTRODUCTION

Today, the use of power electronic devices is increasing day by day. Most power electronic devices are nonlinear in nature. Mostly the power electronic converters are used for rectification (AC to DC conversion) and inversion (DC to AC) purposes. The features of voltage and current waveforms in power systems shift from pure sinusoidal constant amplitude signals due to the existence of non-linear loads and the growing number of distributed and generation power systems (DGPS) in electrical grids. Accurate measurement of electrical power amounts under these circumstances necessitates the use of sophisticated signal processing techniques. Over the past few decades, non-linear loads have become more influential in electrical power systems. Such electrical loads can be found in rectification front-ends of motor drives, electronic ballasts for discharge lamps, personal computers, or electrical appliances. These electrical loads introduce non-sinusoidal current consumption patterns (current harmonics) [1].In power systems, harmonics are signals that are overlaid on the fundamental signal and have integer multiples of the fundamental frequency. Electric utility providers should provide a constant frequency and constant magnitude supply to their clients that is 50/60 Hz, the fundamental frequency [2].

2. HARMONIC SOURCES

The main sources of harmonics are power semiconductor devices, electric furnaces, fluorescent lamps, rotating machines, saturated devices like transformers, variable frequency drives (VFDs) etc. in modern industry. These sources are discussed in the following sections.

2.1 Supply Side Sources

Supply-ended equipments produce the harmonics. For example: three phase transformer, uninterruptable power supply (UPS) and Single-phase switch mode power supplies (SMPS). These are discussed below:

2.1.1 Three Phase Transformer

A transformer is a harmonic source due to its non-linear magnetic material characteristic. The transformer can acquire in core saturation conditions in either of the subsequent cases [3] : The first core saturation condition can arise when transformer operating above rated voltage and during peak demand periods. The second core saturation condition can arise when the transformer operates above rated voltage and occur during light load conditions. Especially the feeder voltage increases above nominal voltage, when the capacitor banks are not disconnected accordingly. Under transformer saturation conditions, distorted current waveform the transformer operates on the saturation condition so, a nonlinear magnetizing current occurs which contains odd harmonics [4].When load is increases then this effect becomes more prominent. In an ideal lossless core, hysteresis losses are not produced. Hysteresis losses are produced through the magnetizing current of steel sheet material used in the construction of the core. Yet under this situation, plot the characteristics between the magnetizing current vs. time for each flux value measured, the resultant current waveform would be non-sinusoidal. The distortion is produced due to odd harmonics such as 3rd , 9^{th,} 15th, etc, but normally due to third harmonic [5].

The magnetizing current must take a non-sinusoidal shape in 3 phase transformers with magnetically independent phases, such as a bank of single phase transformers and 3 phase shell type transformers, in order to provide sinusoidal flux [6]. This leads to a number of undesirable effects. The phase magnetizing currents must have the third and higher harmonics since a sinusoidal flux must be created.

2.1.2 Switch-Mode Power Supplies (SMPS):
Switch-mode power supplies (SMPS) are controlled power sources with AC-DC conversion devices that change alternating current waveform into direct current waveform. Issues related to power quality and harmonic supply network currents are brought on by the SMPS's nonlinear components [7] .Voltage distortion and a decline in the network's power factor are caused by these current harmonics. The transformers become overloaded as a result of voltage distortion and current harmonics. Their reliability suffers, and their lifespan is shortened. Electrical appliances get too hot from excessive harmonic emission, which also makes more noise. Additionally, safety devices like relays and circuit breakers are susceptible to failure. These harmonics not only degrade the network but also the efficiency of the SMPS. Therefore, it is crucial to calculate the effect of the network's nonlinear power supply-added current harmonics emission. However, there are a number of power system-related variables that could have an impact on estimates of the power quality. Harmonic emission in the grid can change depending on supply voltage variation and load operating modes [8].

2.1.3 Uninterrupted Power Supply (UPS): An electrical device called a UPS is used to supply backup power in the event that the input power source fails. During power outages or voltage sags, it makes sure that connected equipment has a constant source of electricity [9].

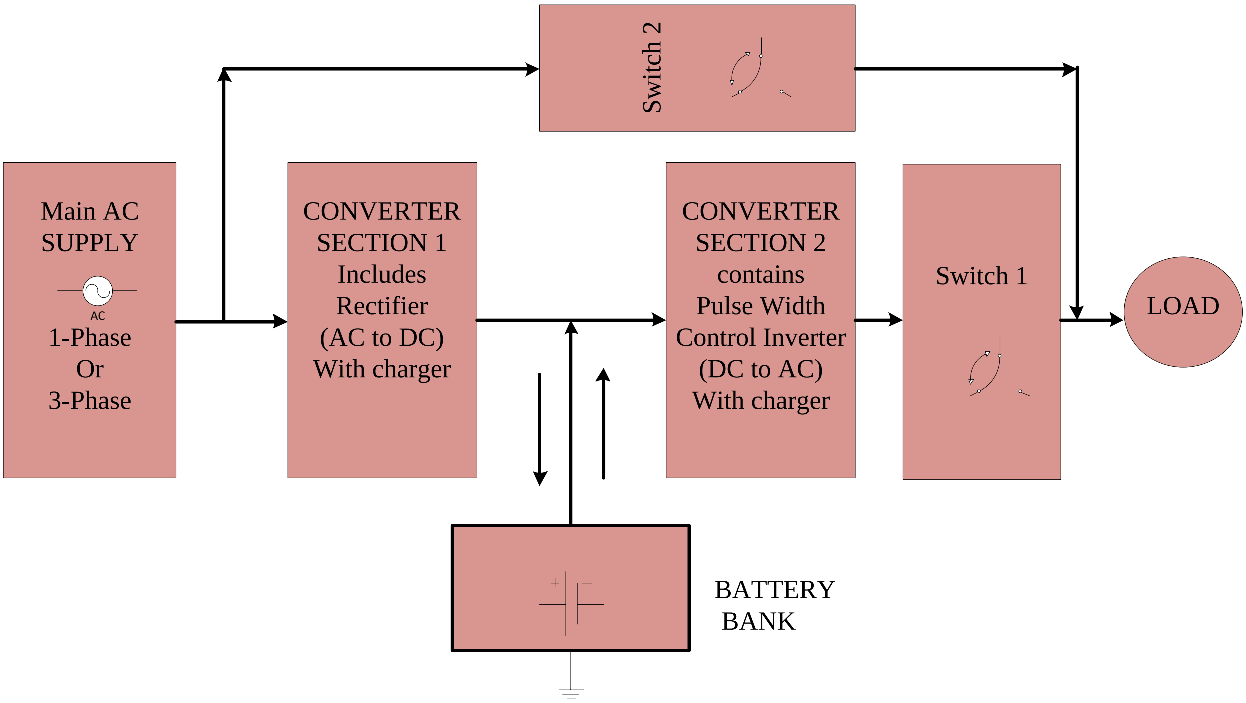

Figure 1. The schematic diagram of each section of UPS with bypass circuit

When UPS systems receive electricity from the utility grid, input harmonics may have an impact[9][10]. The presence of nonlinear loads in the UPS's electrical circuit might cause harmonic currents to enter the system, which may cause voltage distortion or UPS overheating. The UPS is connected to this external source of alternating current (AC) power as represented above in the figure 1.1. Utility power from the electrical grid or generator power is both options. The direct current (DC) is produced when the rectifier transforms the incoming AC electricity from the AC input. This DC electricity is used to power the inverter and charge the UPS battery. A crucial component of the UPS is its battery. The Electrical energy is converted from chemical energy. When the AC input is present and functioning normally, the rectifier maintains the battery charged. The inverter is powered by the battery so that it can keep running the load even in the event of a power outage or other disruption. The battery's DC electricity must be transformed into usable AC power by the inverter. During a power outage or when the incoming AC power is inconsistent, this component powers the associated load. Computers, servers, delicate electronic equipment, and other items are the output load.

There may be a bypass circuit in some UPS systems that allows the AC input power to bypass the rectifier and inverter and go directly to the output load. This could be helpful in the event that the UPS malfunctions or for maintenance needs.

3. Power Control Devices

In a distribution power system, the power converters are the main sources of harmonics. These power converters are used to rectify the 50/60 Hz AC into DC power. In DC power applications voltage is adjusted by varying the firing angle of electronic switching devices. Power converters like AC-DC, AC-AC, DC-AC consist of at least one power electronic device such as: diode, transistor, SCR, IGBTs, etc. The power electronic device allows the current to flow only in one direction and blocks the current in opposite direction. For this reason current is not sinusoidal for a longer time this is also known as the harmonic current. Inverters are used to converts DC into AC. The converters are classified into some categories, which are given below:

Large size power converters: Large power converters are available in mega volt-ampere range and are used to convert AC to DC [11]. On DC side, these converters operate as a harmonic voltage source. On the other hand, on AC side these converters and operate as a harmonic current source. These converters are widely used in electric utility applications [12].

Medium size power converters: Medium size power converters are available in kilo volt- ampere size. In the modern industrial areas, these types of converters are widely used [13] .Applications of these types of converters are given below:

- Speed control of AC induction motor
- Speed control of DC motor

Low size power converters: Low power converters are available in low kilo volt-ampere size. Applications of low power converters are given below:

- Uninterruptible power supply (UPS) units are used in hospitals.
- Discharge lamps are used in street lighting, aircraft, and industries.
- Television sets are used for entertainment.
- Computers are used in all fields.
- Fax machines are used in medical prescriptions, printing documents, etc [14].

3.1.1 Harmonics due to Rectifiers:

Unwanted electrical phenomena known as harmonics due to rectifiers occur in power systems when rectifiers are used to convert alternating current (AC) into direct current (DC). Rectifiers are electrical parts that are often employed in a variety of applications, including battery charging systems, renewable energy systems based on inverters, and power supplies for electronic devices like solar panels. Rectifiers give the power system non-linear characteristics when they are applied. The current drawn and the applied voltage are not directly proportional in a non-linear device like a rectifier. Harmonics are formed because of this nonlinearity[15].

3.1.2 Harmonics due to Cyclo-converters: In order to change alternating current (AC) from one frequency to another, cycloconverters are used. They are frequently employed in situations where AC motors must be controlled to run at a variable speed, such as in industrial drives and some renewable energy systems. The output voltage and current waveforms of cyclo-converters can produce harmonics [16][17][18].

3.1.3 Variable Frequency Drives: The use of VFDs is increasing day by day. Electric motors (EMs) supplied by variable frequency drives (VFDs) are used extensively in the automobile, ship, aircraft, and other industries because of their energy-saving, cost-effective, and reliable speed control features [19][20].

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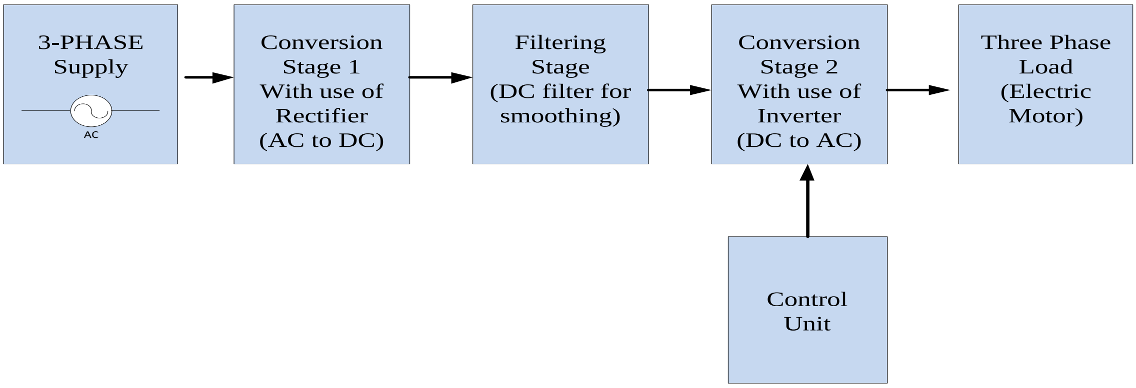

Figure 2. The three-phase motor with variable frequency drives

But when VFD-fed EMs are in use, the applied voltage waveform may develop harmonic components, which over time may cause the stator winding's insulation to fail prematurely. Online condition monitoring of VFD-fed EMs is necessary to detect any potential winding insulation failure in advance and to schedule routine repair tasks [21]. These are used to control the speed of motors. VFDs draw current from the line only while the line voltage is larger than the DC Bus voltage inside the variable frequency drive. This happens only close to the peaks of the sinusoidal wave [22]. Accordingly, all the current is drawn at higher frequencies)[23].The non-linear type of load is connected with variable frequency drives, which is constituted in figure 1.2.
The variable frequency drives are also used to control the speed of motors, reasons are given below:

- Improve the efficiency of the system
- Energy saving
- Conversion of power
- Reduce the noise like as fan and pumps
- Decrease the mechanical stress
- Increase the life of motors
- Improve reliability of the system
- Improve power factor
- Reduce maintenance cost
- Soft starting

4. Harmonic Production from Non-Linear Loads
The development of models that predict the input current harmonics of continuously variable electronic loads, such variable speed drives (VSDs) and rectifier loads, has received significant and fruitful effort[24][25].

4.1 Fluorescent lamps: High-efficiency fluorescent lighting with electronic ballasts is used for commercial places such as hospitals, internet data centers, offices and department stores. Fluorescent lamps have non-linear characteristics, which produce odd harmonics. Electronic ballasts operate at higher frequencies and produce harmonics. These chokes also produce harmonics due to non-linear behavior that has negative dynamic resistance. The magnetic core inductors or chokes are used to limit the current[26].

LED Lamps' Principle of Operation
LEDs must be powered by the AC mains in addition to a low DC voltage source that can provide a steady current source. As a result, a converter must be used to regulate the voltage and manage the current provided to the LEDs [26] . The block diagram of a typical power supply for LED lighting with dimming control is shown in Fig.1.3.

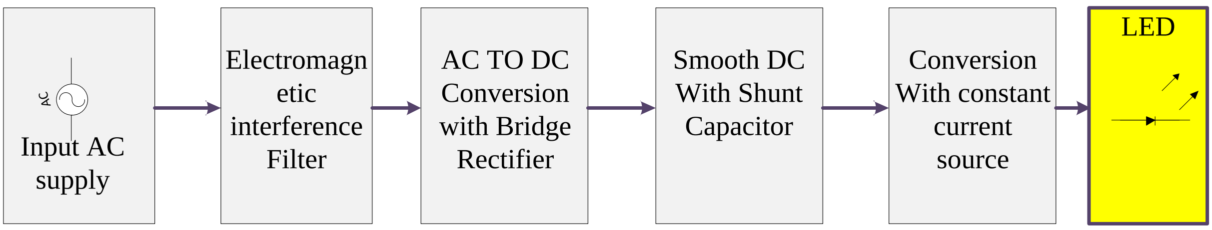

Figure 3. The connection diagram of electronic equipments of Light Emitting Diode

It has an EMI (Electromagnetic interference) filter, a rectifier with a smoothing capacitor, and a DC to DC converter with constant current control. It is powered by AC line input voltage. One LED bulb has a modest input power, but a large number of LED lamps can have an impact on the quality of the electricity. The LED lights produce harmonic distortion on the feeders in conjunction with the dimmer function. Harmonic distortion of the current and voltage waveforms is typically used to represent how much a waveform deviates from a perfect sinusoidal waveform. Like any other equipment, LED bulbs also have to go by a number of regulations that are specific to the item [27][28].

4.2 Rotating Machine Harmonics

Harmonic current can develop in the winding patterns of a three-phase winding of a rotating machine due to rotor slots and slight irregularities. These harmonic currents induce an electromotive force on the stator winding. This EMF is induced at a frequency equal to the ratio of speed/wavelength. In the machine, the resulting distribution of magneto motive forces produces harmonics. Upon magnetic core saturation, additional harmonic currents can be produced. Though, harmonic current produces by rotating machines is typically smaller than those produced when the rotating machines are connected with variable frequency drives (VFDs)[29][24]. The harmonic torques, vibrations, and noise or unwanted signals are produced through the interaction between the harmonic flux and harmonic current which is produced by the rotor windings, magnetic saturation or inequalities in the length of an air gap and circulates harmonic current or voltage respectively.

Harmonics torques are produced by sinusoidal currents which are carried by three-phase winding in the form of $\mathbf{h = 6k \pm 1}$, the harmonics travel or rotate in a similar direction in which direction the fundamental wave is rotating .whereas,

K = positive integer for example 1, 2, 3

In the case of the opposite direction of both h = 6k + 1 and h = 6k – 1 then the fundamental wave is rotates in opposite direction. The speed of h^{th} harmonic is given as

$$N_{s(h)} = \frac{N_S}{h} = \frac{120f}{h \times P}$$

Where, f is the supply frequency and p is a number of poles of the stator winding.

4.3 Arcing Devices: Electric arcing devices have non-linear voltage and current characteristics**.** Short circuit current decreases the arc ignition voltage, which is limited by the use of impedance of power system. Arc furnace has non-linear arc current, which produces harmonics. Types of arcing devices that produce the harmonic distortion such as:

- Electric arc furnaces are used in steel mills.
- Discharge type lighting is used in industrial areas as well as residential areas.

4.4 TV Receivers: TV receivers are sources of harmonics that produce third, fifth, seventh and ninth order harmonics. electricity-efficient liquid crystal display (LCD) and light emitting diode (LED) televisions are replacing direct view and digital light processing (DLP) televisions as a result of global initiatives to conserve electricity. However, the introduction of harmonics into the power distribution system by these energy-saving gadgets jeopardises the quality of the power [28].

4.5 PC and Printer: Personal computers and printers are other sources of harmonics that produce third order (72%), fifth-order (60%), seventh-order (40%), and ninth-order (22.6%) harmonics [30].

5. New Sources for Harmonics

The electricity network is exposed to new harmonic sources in addition to the system's established sources of harmonics.

5.1 HVDC Systems: Harmonics are a prevalent problem that can significantly affect the reliability and efficiency of the electrical grid in high-voltage direct current (HVDC) systems. By converting alternating current (AC) to direct current (DC) at the sending end and back to AC at the receiving end, high-voltage direct current (HVDC) transmission is used to carry enormous amounts of electrical power across vast distances. Harmonics in HVDC systems refer to understand electrical disturbances or frequencies that can arise during the operation of these systems [31]. HVDC systems are engineered for long-distance electricity transmission with lower losses compared to traditional AC (Alternating Current) systems. However, they are susceptible to the generation of harmonics, which can have various origins and consequences.

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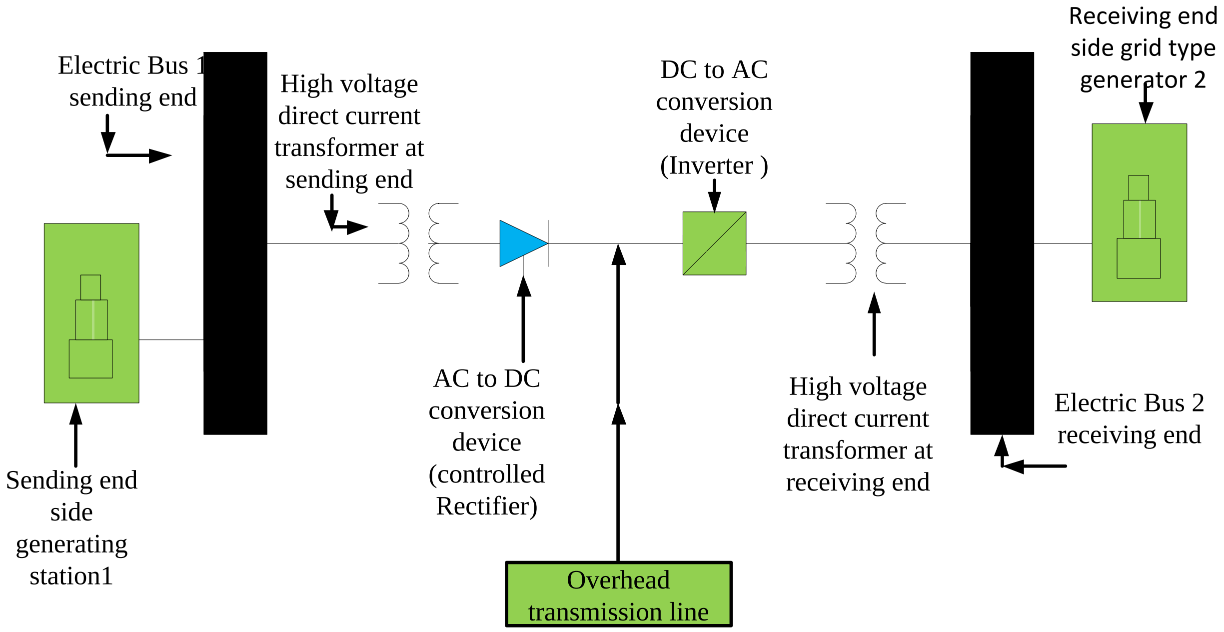

Figure 4. The block diagram of HVDC network with power electronic unit

5.1.1 Converter operations: Harmonics can be produced during the conversion process in HVDC systems. HVDC systems employ power electronic converters to change AC to DC at the transmitting end and then back to AC at the receiving end that is shown in figure 1.4. These converters can introduce harmonics due to their switching actions.

5.1.2 Switching devices: The semiconductor devices like thyristors or insulated gate bipolar transistors (IGBTs) used in the converters can generate harmonics as they turn on and off. This switching action results in sharp voltage and current transitions, giving rise to harmonics[32].

5.1.3 Impacts on AC systems: HVDC systems can also influence the connected AC system, leading to harmonics. These impacts can include voltage distortions and harmonics on the AC side, especially if the AC and DC systems are not adequately synchronized[23].

5.2 Electric Vehicles: the creation and future widespread use of electric cars, which need a lot of electricity rectification to charge their batteries. Due to conversion process harmonics are produced in the circuit[33] .Harmonics related to electric vehicles (EVs) pertain to undesirable electrical disturbances or frequencies that can arise due to the charging and operation of these vehicles. As EVs become more widespread, it is crucial to comprehend the origins and consequences of harmonics in the context:

5.2.1 Charging systems: The electric vehicles are typically charged through power electronic converters. These converters play a crucial role in converting alternating current(AC) power from the electrical grid into the direct current(DC) power needed for charging EV batteries, which are indicated below in the figure 1.5. However, the switching action of these power electronics in the charger can give rise to harmonics, which are unwelcome electrical disturbance.

5.2.2 Rectification: during the conversion of AC power into DC power for charging, a process called rectification occurs. This process can introduce harmonics into the electrical supply. The rectifier circuitry, commonly found in EV chargers, can contribute to the generation of electrical disturbance due to its switching behavior.

5.2.3 Battery inverters: In some electric vehicles, particularly those equipped with DC fast-charging capabilities, battery inverters are used to convert DC power from the battery into AC power to drive the electric motor. These inverters can also introduce harmonics during the conversion process.

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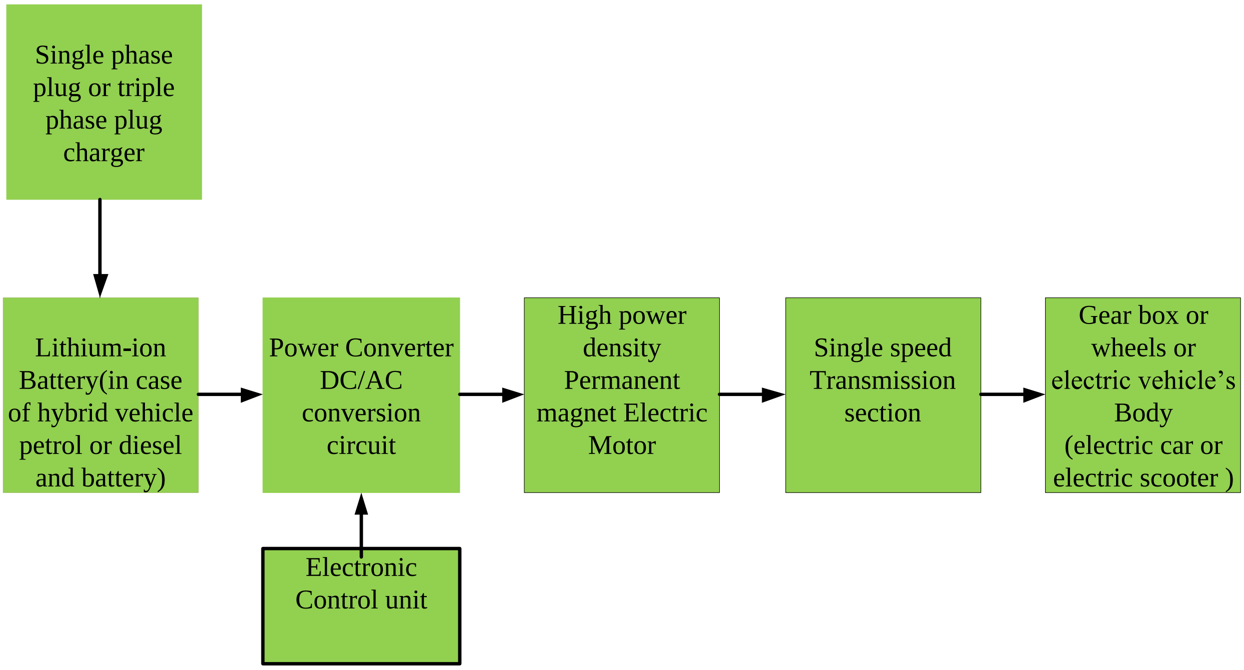

Figure 5. The block diagram of electric vehicles with control unit

5.2.4 Grid impact: charging multiple electric vehicles simultaneously within a localized area can result in a surge in power demand, potentially causing harmonics to be injected into the electrical grid. This can impact the quality of power supplied to other consumers connected to the same grid.

5.3 Energy Conversion Devices: Energy-saving measures that use power semiconductor devices and switching, such as those for enhanced motor efficiency and load matching. These devices frequently produce harmonic-rich voltage and current waveforms with unusual shapes. the potential application of dc/ac power converter-required direct energy conversion technologies like magneto hydrodynamics, storage batteries, and fuel cells.

5.4 Hybrid systems: When the integrated wind and solar power generation system converters are connected to distribution systems, harmonics are produced by the conversion devices. Some other sources are static-var compensators, pulse-burst-modulated heating elements for large furnaces [34].

6. Effects of Harmonics

Each of these origins of harmonics can lead to various consequences within electrical systems. These consequences encompass a decline in the quality of electrical power, increased energy losses, equipment overheating, and disturbances that can affect decline electronic devices. Effectively handling and lessening these repercussions is vital to upload a consistent and dependable supply of electrical power. Some of effects are discussed in the table 1.

Table 1. Effects of harmonics on the equipments as well as power quality

Effects of Harmonics	On Equipment	On Power Quality
Equipment Overheating	Increased heat generation in transformer, motors, and cables, potentially shortening their operational lifespan**.**	Voltage waveforms become distorted and may lead to unbalanced supply, low power factor. .
Reduced equipment lifespan	Accelerated wear and tear of components, necessitating more frequent maintenance and replacement.	Escalated energy losses and elevated utility bills**.**
Interference with electronics and increased energy costs	Potential malfunctioning or harm to sensitive electronic devices and control systems	Lighting flicker and instability within electrical systems
Voltage distortion and current overloading	Equipment malfunctioning or disruptions caused by voltage sags and swells.	Heightened vulnerability to voltage sags, surges and Possible harm to other interconnected loads.

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7. HARMONIC ANALYSIS AND DETECTION METHODS

Detection of harmonics in power systems is crucial for ensuring the reliability and efficiency of electrical networks. Harmonics are unwanted frequencies that can result from nonlinear loads, such as power electronic devices and variable speed drives, and can cause voltage distortion, equipment overheating, and operational inefficiencies in electrical systems, such as power grids and electronic devices. Detecting and analyzing these harmonics is essential for maintaining power quality and ensuring the reliability of electrical networks. Several methods are employed to detect and analyze harmonics in power systems.

7.1 Indices for Power Quality in the Presence of Harmonic Distortion

Power quality indices are essential metrics used to evaluate and ensure the performance and reliability of electrical power systems, especially in the presence of harmonic distortion. Harmonics are generated by non-linear loads and can significantly impact the overall power quality, causing issues like overheating of equipment, increased losses, and malfunctioning of sensitive devices. To manage and mitigate these issues, various indices are used to measure and analyze power quality in systems affected by harmonic distortion.

7.1.1 Total Harmonic Distortion (THD) Measurement:

THD measures the total harmonic content relative to the fundamental frequency in a voltage or current waveform. It is calculated using the RMS values of harmonic components and the fundamental component. THD provides a single numerical value representing the extent of harmonic distortion in the waveform. This metric is widely used for evaluating compliance with power quality standards and quantifying harmonic pollution levels[35][36].

Total harmonic distortion of voltage parameter indicates the total amount of voltage distortion. It is determined by computing the ratio of distorted or harmonic voltage to the non-harmonic or fundamental voltage, and can be expressed as:

$$)v = \frac{\sum_2^{40} Vn^2}{\text{amental voltage}}$$

Where, V_n is the voltage magnitude of n^{th} order harmonic.

7.1.2 Total Demand Distortion (TDD) Measurement:

This concept is widely employed in North America concerning harmonics. It represents the ratio of harmonic current to the fundamental current at full load. The full load current refers to the total non-harmonic current consumed by all loads in the system at peak demand.

$$TDD = \frac{\sum_2^{40} In^2}{\text{Demand or load current}}$$

Where, I_n is the current of n^{th} order harmonic.

7.2 Harmonic Analysis Method

Harmonic analysis is a branch of mathematics that studies the representation of functions or signals as the superposition of basic waves, and the study and generalization of the notions of Fourier series and Fourier transforms (i.e., decomposition of functions into harmonics). It has applications in many fields, including engineering, physics, and signal processing. The method allows complex signals to be broken down into simpler components, making it easier to analyse and manipulate them, as discussed below:

7.2.1 Discrete Fourier Transform (DFT):

The Discrete Fourier Transform (DFT) is a mathematical technique used to analyze discrete signals, providing amplitude and phase details of specific harmonics. This method is applicable in both single-phase and three-phase systems, relying on current measurements.

7.2.2 Fast Fourier Transform (FFT):

The Fast Fourier Transform (FFT) plays a crucial role in harmonic detection within electrical systems and signal processing applications. The FFT is particularly well-suited for harmonic detection due to its efficiency in computing the Discrete Fourier Transform (DFT) of discrete-time signals. The FFT decomposes a signal into its constituent frequencies, revealing the presence and magnitude of harmonics. Each harmonic component appears as a peak in the FFT output corresponding to its frequency. Before applying FFT for harmonic detection, signals are often windowed to reduce spectral leakage and improve frequency resolution. Various windowing techniques can be used depending on the application requirements[36][37].

By examining the amplitudes and phases of FFT output bins, engineers can assess the severity of harmonic distortion in electrical waveforms. This information helps in designing effective mitigation strategies. In power systems, FFT-based harmonic detection is used in devices such as power quality analyzers, energy meters, and oscilloscopes to monitor harmonic levels, identify sources of harmonics, and ensure compliance with international standards (e.g., IEEE 519).

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Therefore, The FFT is a powerful tool for harmonic detection, providing engineers and technicians with valuable insights into the spectral characteristics of signals. Its computational efficiency and accuracy make it indispensable for maintaining the integrity and efficiency of electrical systems in various industrial and commercial settings.[37], [38]

7.2.3 Iterative Discrete Fourier Transform (IDFT)
The Iterative Discrete Fourier Transform (IDFT) is a method used for detecting harmonics in signals, particularly in scenarios where traditional Fourier analysis techniques like the FFT may not be directly applicable or suitable. Unlike the Fast Fourier Transform (FFT), which uses a highly optimized algorithm to compute the Discrete Fourier Transform (DFT) efficiently, the IDFT approach involves iterative calculations that may offer benefits in certain specialized applications.
In summary, while the FFT remains the standard for harmonic detection in most applications due to its speed and efficiency, the Iterative Discrete Fourier Transform (IDFT) offers an alternative method that can be tailored to specific needs where iterative computation and customization are advantageous.

7.2.4 Resonance and Impedance Analysis:
Harmonic distortions can cause resonance conditions in power system components like capacitors, transformers, and cables. Resonance and impedance analysis involves evaluating the impedance characteristics of these components across different frequencies. Engineers analyze impedance profiles to identify resonance frequencies where harmonic amplification occurs, potentially leading to equipment failures or overheating.

7.3 Harmonic Measurement Instruments
Harmonic measurement instruments are essential tools used to analyze and measure harmonic distortion in electrical systems. Harmonic distortion can have significant impact on the performance, efficiency, and reliability of power systems and electronic devices. These instruments help in identifying, quantifying, and mitigating harmonics to ensure the proper functioning of electrical systems.

7.3.1 Harmonic Distortion Analyzer or Power Quality Analyzer:
Harmonic distortion analyzers are specialized instruments designed for comprehensive power quality analysis. They measure and analyze harmonic distortion levels in voltage and current waveforms. These analyzers can graphically display harmonic content, provide THD values, and identify specific harmonic frequencies present in the system.
Continuous monitoring of power quality parameters such as voltage, current, and frequency over time is essential for detecting and analyzing harmonic distortions shows in figure 1.6. Power quality monitors record waveform data, enabling engineers to analyze trends, identify intermittent harmonic issues, and assess the overall impact of harmonics on the power system.

7.3.2 Oscilloscopes with FFT Capability
Oscilloscopes equipped with Fast Fourier Transform (FFT) capabilities can be used to perform harmonic analysis. By capturing time-domain signals and converting them to the frequency domain using FFT, these oscilloscopes can display the harmonic spectrum of a signal. While not as specialized as harmonic analyzers, oscilloscopes with FFT are valuable tools for visualizing and analyzing harmonic content in various applications.

Conclusion
In this paper, many harmonic sources in the power system are addressed. The principal sources of harmonics in the power system include three-phase transformers, rotating equipment, power-regulating devices, LEDs, UPSs, variable frequency drives, etc. Harmonics create distorted current and voltage waveforms that overload cables, transformers, and motors, which can result in heat and, in severe circumstances, fire.
To sum up, harmonics originating from different sources in electrical systems can lead to a wide range of consequences, affecting equipment and the quality of power. These outcomes involve deterioration in power quality, increased energy losses, equipment overheating, and disruptions to sensitive electronic devices. It is imperative to effectively manage and mitigate these harmonics to ensure a consistent and dependable supply of electrical power. By addressing these challenges and adhering to established standards and best practices, maintain the efficiency of electrical systems, ensuring the delivery of high-quality power to meet diverse needs, all while averting potential disruptions and equipment damage.

LIST OF ABBREVIATIONS

AC	Alternating Current
ASD	Adjustable-Speed Drives
DC	Direct Current
DFT	Discrete Fourier Transform
DLP	Digital Light Processing

EV	Electric Vehicles
FFT	Fast Fourier Transform
HVDC	High Voltage Direct Current
IDFT	Iterative Discrete Fourier Transform
IGBTs	Insulated-Gate Bipolar Transistor
LED	Light Emitting Diode
PV	Photovoltaic
SCR	Silicon Controlled Rectifier
SMPS	Switch Mode Power Supplies
THD	Total Harmonic Distortion
TDD	Total Demand Distortion
UPS	Uninterruptable Power Supply
VFD	Variable Frequency Drives
VSD	Variable Speed Drives

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