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A Review Paper on Harmonic Mitigation Techniques

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Abstract:
In today's world, power system networks are facing a significant challenge due to the increase in harmonic distortion levels. Harmonics in power systems are unwanted frequencies that can result in significant voltage distortion, increased energy losses, and equipment damage. Therefore, the reduction of harmonic distortion levels in power systems is of utmost importance. This research paper focuses on various methods and techniques for harmonic reduction in power systems, which include passive, active, and hybrid filters. This review paper provides a comprehensive overview of various techniques used for mitigating harmonic distortions in power systems. The review highlights the importance of harmonic mitigation in modern power systems and emphasizes the need for proper selection and application of harmonic mitigation techniques. The effectiveness and limitations of each technique will be discussed, and a comparison of the different methods will be presented.
Keywords: Harmonics, Distortion, Passive, Active, Hybrid, Filters,

Introduction:
The growth of modern technology and the increasing number of non-linear loads in power systems have led to a significant increase in harmonic distortion levels [1-2]. Harmonics can cause power quality problems such as voltage distortion, equipment overheating, increased energy losses, and interference with communication systems [3-5]. Therefore, the reduction of harmonic distortion levels in power systems is crucial. This research paper aims to provide an overview of the various methods and techniques for harmonic reduction in power systems. Harmonics are unwanted frequencies that can be found in electrical power systems. They are the result of non-linear loads, which are devices that draw current in a non-sinusoidal waveform [6-8]. Non-linear loads are becoming more common in power systems due to the increasing use of electronic devices and renewable energy sources [9-10]. The below figure shows the waveform for fundamental, third, and fifth harmonics.

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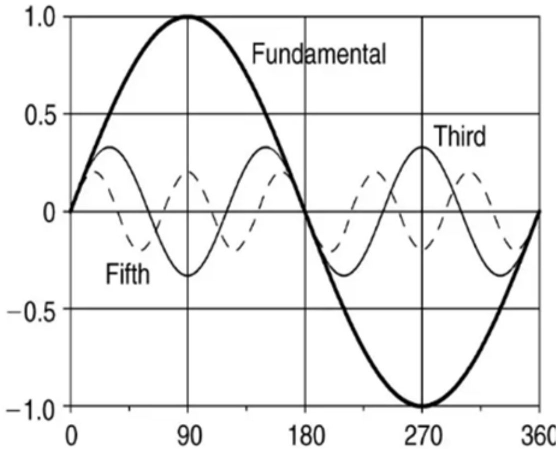

Figure 1 Graph between Degree (in X axis) and Magnitude (in Y axis)

Above figure shows the graph between Degree in X-axis and Magnitude in Y-axis. It is showing basically fundamental, third, and fifth harmonics. Harmonics can cause a range of problems in power systems, such as voltage distortion, equipment overheating, and increased energy losses. Therefore, it is essential to understand the concept of harmonics and their impact on power systems [11]. This understanding can help in the development of effective strategies for reducing harmonic distortion levels and improving the overall power system performance.

Harmonic Reduction Techniques:
There are several methods and techniques for harmonic reduction in power systems. These include passive filters, active filters, and hybrid filters.

Passive Filters:
A harmonic passive filter is an electronic circuit designed to eliminate or reduce the presence of harmonics in an electrical power system. Harmonics are unwanted, high-frequency currents or voltages that can cause problems in power systems such as overheating of equipment, increased energy losses, and even equipment failures.

The harmonic passive filter works by providing an alternative path for the harmonic currents to flow. This alternative path is created using reactive components such as capacitors and inductors that have the ability to store and release energy in a cyclic manner, effectively cancelling out the harmonic components of the current or voltage [12].

The basic principle behind a harmonic passive filter is that the reactive components in the filter act as a shunt to the harmonic currents, allowing them to flow through the filter instead of the power system. This prevents the harmonic currents from entering the power system and causing problems. The passive harmonic filter with a power system is shown below in figure no. 1.

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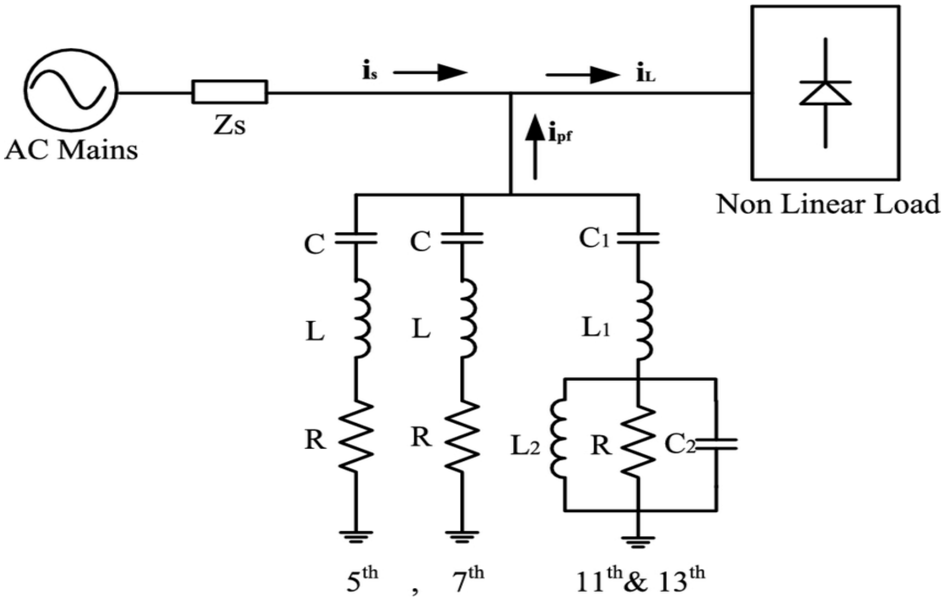

Figure 1. Passive Harmonic Filter with power system

Harmonic passive filters can be designed for specific harmonic frequencies and are commonly used in power systems with nonlinear loads such as variable frequency drives, rectifiers, and other types of electronic equipment. By reducing or eliminating the harmonic currents, harmonic passive filters can improve the power quality of the system and increase the efficiency and reliability of the equipment. Over all one can say that Passive filters are designed to reduce harmonic distortion levels by introducing a network of inductors, capacitors, and resistors to the power system. Passive filters are effective in reducing low-order harmonics but are less effective at reducing high-order harmonics. Passive filters are simple, cost-effective, and do not require any additional power source. However, they have limited harmonic reduction capabilities, and their performance is dependent on the load characteristics.

Passive filters are a popular technique for harmonic mitigation in power systems, primarily because they are relatively low-cost and simple to install. One of the major advantages of passive filters is that they are low-noise devices and generate minimal electromagnetic interference, making them ideal for applications that require low EMI. Passive filters are also highly reliable and have a long lifespan, typically lasting for 15-20 years without any major maintenance. However, passive filters do have some limitations that need to be considered. For example, their effectiveness is limited to a specific frequency range, and they can cause a voltage drop in the system, which can impact the performance of other connected equipment. Additionally, passive filters can be bulky and heavy, making them challenging to install in some applications. Finally, if not designed and installed correctly, passive filters can experience resonance issues, which can cause additional harmonic distortions. In conclusion, while passive filters offer a cost-effective solution for harmonic mitigation, their limitations must be carefully considered when selecting and installing them in a power system.

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Active Filters:

A harmonic active filter is an electronic device used to mitigate harmonic distortion in electrical power systems. Unlike passive filters, which use reactive components to shunt harmonic currents, active filters use electronic switching devices and control algorithms to actively inject counteracting currents into the system, cancelling out the harmonic components of the load current or voltage [13].

Active filters are electronic devices that provide an effective solution for mitigating harmonic distortions in power systems. They use advanced control algorithms and electronic components to generate compensating currents that cancel out the harmonic currents, resulting in reduced harmonic distortion. Active filters offer several advantages, but also have some limitations that need to be considered. Active filters are highly effective in mitigating harmonic distortions across a wide range of frequencies, providing superior harmonic reduction compared to passive filters. Active filters improve power quality by reducing the THD (Total Harmonic Distortion) and improving the power factor, resulting in a more stable and efficient power system[14]. It can adapt to changes in the harmonic content in real-time, providing immediate harmonic compensation and dynamic response to load and network changes. Active filters are relatively small and lightweight, making them easy to install in confined spaces. Active filters can be configured to meet specific application requirements using simple software tools, providing flexibility in harmonic mitigation. Whereas Active filters are more expensive than passive filters, making them less attractive for low-budget applications. Active filters require a more complex control system that involves advanced algorithms and sensing technologies, making them less accessible to inexperienced users. Active filters generate electromagnetic interference that can affect the performance of other devices connected to the same power source. Active filters require regular maintenance to ensure proper operation and avoid potential failures due to the complex nature of their design.

In conclusion, active filters offer a high-performance solution for harmonic mitigation in power systems, but they come with a higher cost and require more expertise to design, install, and maintain. However, their dynamic response, improved power quality, and configurability make them an attractive option for high-end applications [15]. The choice between active and passive filters will depend on the specific application requirements and the available budget.

There are two main types of harmonic active filters:

Current-source active filters or Series Active Filter:

In this type, the active filter is connected in parallel with the load, and it injects a current into the system that is equal and opposite to the harmonic current produced by the load. This cancels out the harmonic current and reduces the distortion in the system. The Current-source active harmonics filter with a power system is shown below in figure no. 2.

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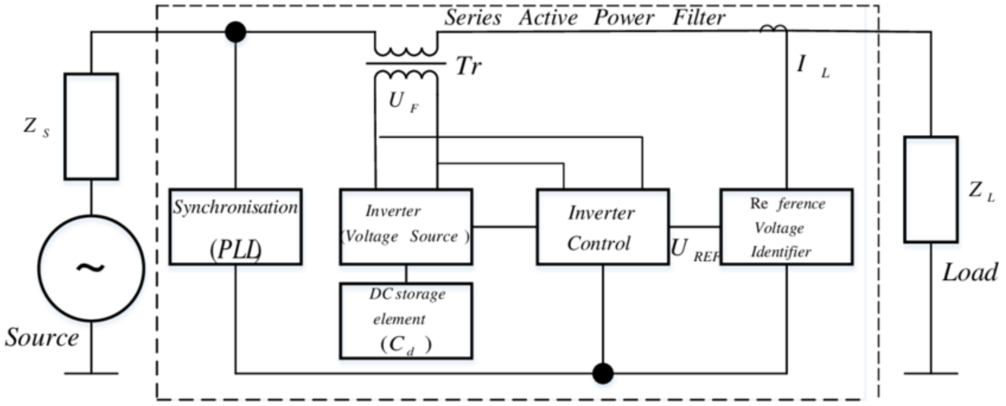

Figure 2. Current-source active filters or Series Active Filter

Voltage-source active filters or Shunt Active Filter:

In this type, the active filter is connected in series with the load, and it injects a voltage into the system that is equal and opposite to the harmonic voltage produced by the load. This cancels out the harmonic voltage and reduces the distortion in the system. The Voltage -source active harmonics filter with a power system is shown below in figure no. 3.

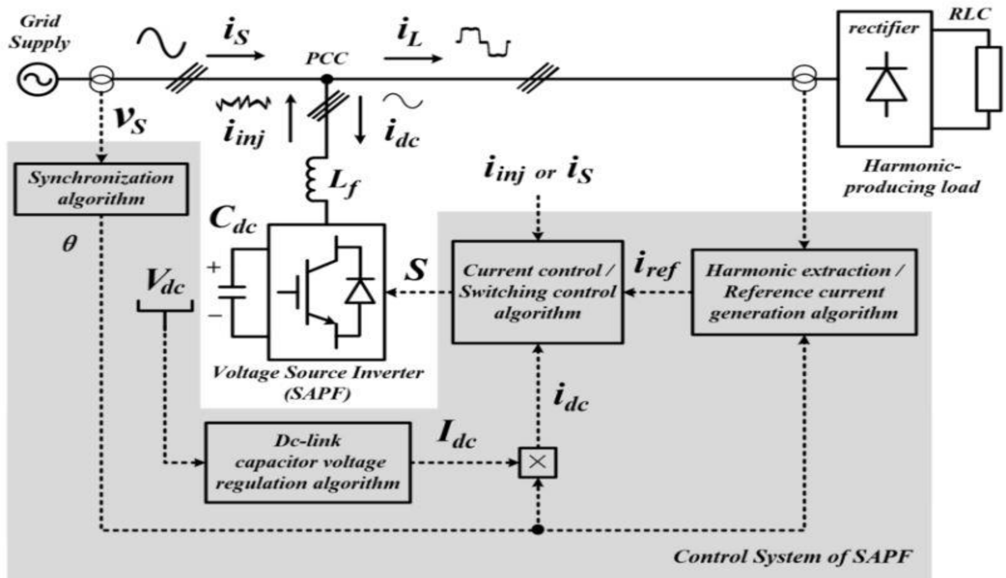

Figure 3. Voltage-source active filters or Shunt Active Filter

The main advantage of harmonic active filters over passive filters is their ability to provide dynamic compensation, which means they can respond quickly to changes in the load and adjust their output accordingly. This makes them particularly effective for systems with rapidly changing loads or where multiple harmonics are present.

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Harmonic active filters are also capable of mitigating both harmonic currents and harmonic voltages, which makes them more versatile than passive filters. They can be used to eliminate harmonic distortion caused by a wide range of nonlinear loads such as variable frequency drives, rectifiers, and inverters [16-18].

Overall, harmonic active filters provide a powerful and effective solution for reducing harmonic distortion in power systems, improving power quality, and increasing the efficiency and reliability of equipment. Active filters use power electronics to reduce harmonic distortion levels in power systems. Active filters are effective in reducing high-order harmonics, and their performance is not dependent on load characteristics. Active filters are more complex and expensive than passive filters, but they offer better harmonic reduction capabilities. Active filters require a power source, and their performance is dependent on the control system.

Hybrid Filters:

A harmonic hybrid filter is an electronic device that combines both passive and active filtering techniques to eliminate harmonic distortion in electrical power systems. It provides the benefits of both passive and active filtering, making it a versatile and effective solution for reducing harmonic distortion in power systems. It provides an effective solution for mitigating harmonic distortions in power systems. They combine the advantages of both passive and active filters while minimizing their limitations. Hybrid filters offer several advantages, but also have some limitations that need to be considered.

Hybrid filters offer superior harmonic reduction compared to passive filters while being less expensive than active filters. Hybrid filters improve power quality by reducing the THD (Total Harmonic Distortion) and improving the power factor, resulting in a more stable and efficient power system. Hybrid filters can adapt to changes in the harmonic content in real-time, providing immediate harmonic compensation and dynamic response to load and network changes. It also generate less electromagnetic interference compared to active filters, minimizing their potential impact on other devices connected to the same power source. Hybrid filters require less maintenance compared to active filters, as they have a simpler control system. Whereas Hybrid filters require a more complex design and control system compared to passive filters, making them less accessible to inexperienced users. Hybrid filters are more expensive than passive filters, making them less attractive for low-budget applications. Hybrid filters have limited configurability compared to active filters, as their design is fixed. Hybrid filters have a limited dynamic range compared to active filters, as their compensating currents are limited by the passive components. In conclusion, hybrid harmonic filters offer a balanced solution for harmonic mitigation in power systems, providing a high-performance option that is less expensive than active filters while being more effective than passive filters. However, their complexity and limited configurability and dynamic range need to be considered when selecting the appropriate harmonic filter for a specific application. The choice between hybrid, active, and passive filters will depend on the

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specific application requirements, the available budget, and the desired level of harmonic reduction.

There are two main types of harmonic hybrid filters:

Active-Parallel Passive-Series (APPS) hybrid filter:

In this type, the active filter is connected in parallel with the load, and the passive filter is connected in series with the load. The Active-Parallel Passive-Series (APPS) hybrid filter with a power system is shown below in figure no. 4. The active filter cancels out the high-frequency harmonic components of the load current, while the passive filter provides low-frequency filtering to mitigate the remaining harmonics.

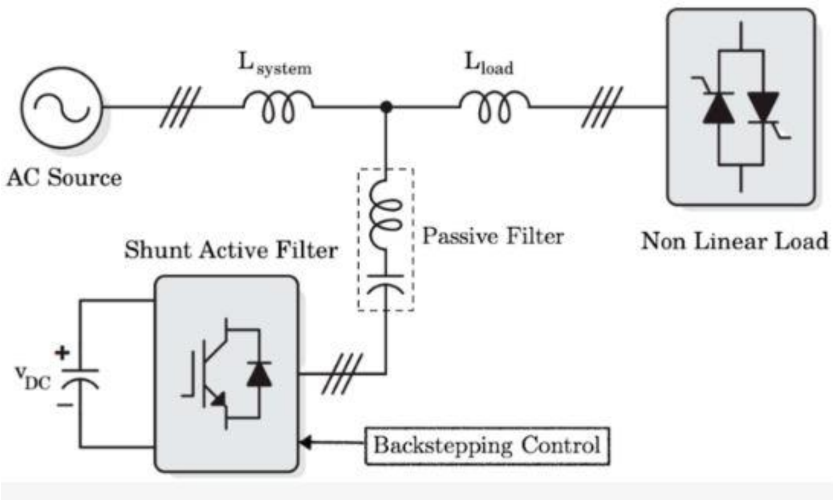

Figure 4. Active-Parallel Passive-Series (APPS) hybrid filter

Active-Series Passive-Parallel (ASPP) hybrid filter:

In this type, the active filter is connected in series with the load and the passive filter is connected in parallel with the load. The Active-Series Passive-Parallel (ASPP) hybrid filter with a power system is shown below in figure no. 5. The active filter cancels out the high-frequency harmonic components of the load voltage, while the passive filter provides low-frequency filtering to mitigate the remaining harmonics.

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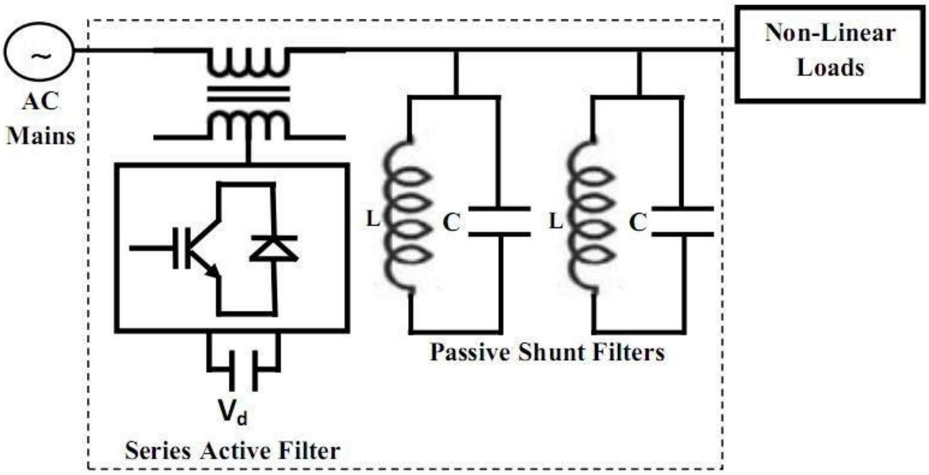

Figure 5. Active-Series Passive-Parallel (ASPP) hybrid filter

The main advantage of harmonic hybrid filters is their ability to provide dynamic compensation and high attenuation of harmonic distortion across a wide frequency range. They are effective for systems with rapidly changing loads or where multiple harmonics are present. They also offer a lower-cost alternative to purely active filters for harmonic mitigation, as the passive filter component reduces the size and complexity of the active filter.

Harmonic hybrid filters work by using a combination of reactive components and electronic switching devices to mitigate harmonic distortion. The passive filter provides low-frequency filtering through the use of reactive components such as capacitors and inductors. The active filter, on the other hand, injects a current or voltage that is equal and opposite to the harmonic component produced by the load, effectively cancelling it out.

Overall, harmonic hybrid filters provide a powerful and effective solution for reducing harmonic distortion in power systems, improving power quality, and increasing the efficiency and reliability of equipment. Hybrid filters combine the advantages of both passive and active filters. They use a combination of passive and active filter elements to reduce harmonic distortion levels in power systems. Hybrid filters offer better harmonic reduction capabilities than passive filters and are less complex and expensive than active filters. However, they require careful design and optimization to achieve the desired harmonic reduction performance.

Theory Used for the Design of any type of Active Filter:
Instantaneous power-based p-q theory is a method for analyzing the power flow in three-phase electrical systems. It is also known as the "instantaneous reactive power" or "p-q" theory.
The p-q theory is based on the concept of instantaneous power, which is the power exchanged between two points at any given instant. In three-phase systems, the instantaneous power is composed of active power, which represents the real power delivered to a load, and reactive

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power, which represents the power that oscillates between the source and the load without being dissipated as real power.
The p-q theory uses a mathematical model of instantaneous power that allows for the calculation of active and reactive power in real time. This model is based on a set of reference signals that are generated from the measured voltage and current signals. These reference signals are then used to calculate the instantaneous power values for each phase.
By using the p-q theory, it is possible to control the flow of power in a three-phase electrical system by adjusting the reactive power. This can be done by adding reactive elements to the system, such as capacitors or inductors, or by using an active power filter to inject or absorb reactive power.
The p-q theory is widely used in power electronics and is an important tool for the design and control of power systems. It is particularly useful for systems with non-linear loads, which can cause harmonic distortion and other power quality issues.

Comparison of Harmonic Reduction Techniques:
Harmonic distortion is a major problem in power systems that can lead to power quality issues and equipment failure. To mitigate this problem, several techniques have been developed for harmonic reduction, including passive, active, and hybrid harmonic filters.
Passive harmonic filters are the simplest and most cost-effective solution for harmonic reduction. They consist of passive components such as inductors, capacitors, and resistors, which are tuned to a specific frequency to filter out harmonics. Passive filters are highly reliable and require minimal maintenance. However, they have limitations in terms of the number of harmonics they can filter and can cause voltage drop and resonance problems.

Active harmonic filters, on the other hand, use active components such as inverters and amplifiers to generate harmonic currents that cancel out the harmonics in the power system. Active filters are more efficient than passive filters in filtering a wide range of harmonics, and they can compensate for power factor and load imbalances. However, active filters are more complex, expensive, and require more maintenance than passive filters.

Hybrid harmonic filters combine the best of both passive and active filters. They use a combination of passive and active components to filter out harmonics, resulting in a more efficient and cost-effective solution. Hybrid filters can filter a wide range of harmonics and compensate for power factor and load imbalances while minimizing the voltage drop and resonance problems that can occur with passive filters.

In conclusion, each harmonic reduction technique has its advantages and disadvantages. Passive filters are simple, reliable, and cost-effective, but have limitations in terms of the number of harmonics they can filter. Active filters are more efficient and can filter a wider range of harmonics, but are more complex and expensive. Hybrid filters offer a balance between the two and provide a more efficient and cost-effective solution for harmonic reduction. The choice of the appropriate harmonic filter technique depends on the specific requirements of the power system, including the number and type of harmonics to be filtered, the cost, and the desired level of maintenance.

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Conclusion:

Harmonic distortion in power systems is a significant challenge that can cause power quality problems and equipment damage. The reduction of harmonic distortion levels is crucial to ensure the reliable and efficient operation of power systems. This research paper has discussed the various methods and techniques for harmonic reduction in power systems, including passive filters, active filters, and hybrid filters. Each technique has its advantages and limitations, and the choice of technique depends on the specific requirements of the power system. Harmonic reduction techniques are an essential aspect of power system design and operation and must be carefully considered to ensure the reliable and efficient operation of power systems.

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