Design and Development of Three Phase Detuned Filter Reactor for Reduction of Harmonic Distortion in Power Systems

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Abstract

Harmonics refers to a form of electrical distortion that can adversely impact power systems, electrical equipment, and the overall quality of power supply. The presence of non-linear loads, such as electronic devices, can cause the current waveform to deviate from the ideal sine wave, resulting in higher frequency currents that are multiples of the fundamental frequency. These distortions can lead to several negative effects, such as reduced power factor, increased energy losses, equipment overheating, and electromagnetic interference. These, in turn, can lower system efficiency, increase energy consumption, and escalate equipment maintenance costs. Several approaches have been developed to address the adverse effects of harmonics, such as the use of filters, capacitors, and other reactive components. These techniques aim to minimize harmonic distortion and improve power supply quality. This paper examines the effectiveness of a 1kVAr detuned reactor in mitigating harmonic distortion in power systems and electrical components. The detuned filter reactor reduces the harmonic distortion actively. It does so by monitoring the harmonic content of the power and injecting a counteracting current to cancel out the harmonic frequencies, creating a subtle "detuning" effect that reduces harmonic distortion. Detuned filter reactors find extensive application in radio and audio equipment, among other fields.

Keywords: Harmonic Distortion, Harmonic filters Power factor, Detuned reactor, Inductor, Capacitor.

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1. Introduction

Harmonic distortions are highly destructive to various components in electrical systems, such as transformers, cables, capacitor banks, and equipment. This distortion leads to different types of signal distortion, such as frequency, amplitude, and phase distortion, which negatively affect the performance of electrical circuits and audio systems. This can cause unwanted noise, interference, distortion, and a decrease in signal quality. The situation has worsened with the increasing use of non-linear devices, such as rectifiers, discharge lamps, UPS, soft starters, and variable speed drives, which increase harmonic distortion and radio frequency interference in the power system. In transformers, harmonic currents can reduce their lifetime, increase the risk of failure, cause core saturation, and affect the performance of other connected equipment, leading to voltage distortion, additional noise, and losses. To address this issue, harmonic filter reactors are connected in series with capacitors in systems where harmonics are present. Due to the non-linear loads, harmonic current flows through the capacitor, but inductive reactance increases with high-frequency harmonics, effectively blocking the harmonic currents. Detuned reactors, when used in series with the capacitors, offer high impedance for harmonics and prevent the risk of capacitor overloading. They prevent harmonic amplification due to resonance and are designed to prevent the flow of harmonic current into the capacitor of power systems, as well as prevent system resonance. The primary objective of developing detuned reactors is to mitigate the harmful effects of harmonic distortion on power systems and equipment. The presence of harmonic distortion causes significant damage to various types of equipment, including capacitor banks, transformers, and cables. Harmonic distortion causes various types of signal distortion, including amplitude distortion, phase distortion, and frequency distortion. It has a negative effect on the performance of electrical circuits and audio systems. It can cause unwanted noise, distortion, and interference, and degrades the quality of the signal.

2. Objective

The proposed system aims to design and develop a highly efficient 1kVAR detuned filter reactor that can effectively mitigate the harmful effects of harmonic distortion in power systems. The primary objective is to prevent the overloading of the capacitor, which is a common issue caused by harmonic currents. This not only protects the capacitor but also safeguards the entire power system connected to it. In addition to protecting the power system, the detuned filter reactor also helps improve the system's power factor by reducing the voltage drop. By reducing the voltage drop, the system's efficiency can be significantly increased, which in turn, reduces energy consumption and costs. The detuned filter reactor helps to enhance the overall system performance by eliminating harmonic distortion and reducing electromagnetic interference.

It effectively blocks the unwanted harmonic frequencies and prevents harmonic amplification, which can cause significant damage to the electrical components and equipment. The development of this 1kVAR detuned filter reactor has the potential to revolutionize power systems and mitigate the negative effects of harmonic distortion, improving the system's efficiency and performance, reducing energy consumption and costs, and protecting the electrical components and equipment from damage

3. Block Diagram

To reduce the negative impact of harmonic distortions, the Detuned reactor, in this case, an inductor, is connected to a three-phase 415-voltage AC power supply. The Detuned filter reactor is then installed with the capacitors, creating a series connection. This connection effectively blocks the high-frequency harmonic currents from passing through the capacitors, as the inductive reactance produced by the detuned reactor offers high impedance to the harmonics. By connecting the capacitors of multiple power systems in series with detuned reactors, various power systems can be protected from the harmful effects of harmonic distortion. This series connection of capacitors and detuned reactors reduces the risk of overloading the capacitors and helps prevent resonance in the power systems. This ultimately leads to better system efficiency and performance, protecting the electrical components and equipment from damage and reducing energy consumption and costs.

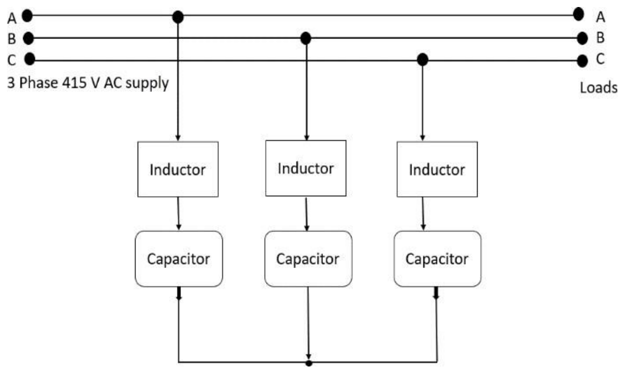

Figure 1. Block Diagram

4. Hardware Used

A. Reactor Core

The reactor core serves the purpose of creating a closed magnetic circuit by arranging laminated sheets or plates of magnetic material, like steel or iron, in a specific geometric pattern. The magnetic field generated by the primary winding is amplified and directed by the core, which induces a corresponding voltage in the secondary winding. The core's laminated structure is designed to minimize energy losses that may occur due to eddy currents that flow through the core as alternating current passes through it. By dividing the core material into thin layers, each separated by a layer of insulation, eddy currents are prevented from flowing within the core and causing excessive heating. The transformer core design plays a critical role in determining its performance. It must effectively transfer the magnetic field between the primary and secondary windings while minimizing energy losses caused by hysteresis and eddy currents. The core's performance can be affected by the materials used, the number of laminations, the thickness of each lamination, and the core's dimensions. The most commonly used core types include E-cores, I-cores, U-cores, and toroidal cores. In this research a Type-16, an E-cored core is used.

Figure 2. Reactor Core

B. Windings

Coils of wire, known as windings, are wrapped around the reactor core to generate a magnetic field and induce the required inductance in the core. Copper or aluminum may be used to create the windings, and their number, gauge, and positioning on the core can all impact the reactor's performance and capacity to mitigate harmonic distortions. The windings of a detuned filter reactor are engineered to provide a predetermined level of impedance at the specific harmonic frequencies of concern. This impedance functions as a filter, minimizing the magnitude of the harmonics and prohibiting them from returning to the electrical system.

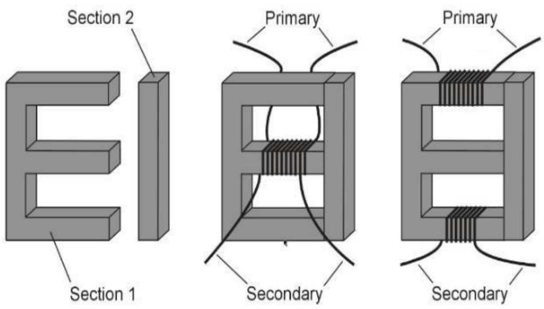

Figure 3. Reactor Windings

C. Capacitor

The capacitive load connected to the detuned filter reactor in a power system plays a crucial role in ensuring the system's optimal functioning. The specifications of the capacitor are designed to meet the specific requirements of the connected load, taking into account the

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various harmonic distortions that may arise due to non-linear loads. The detrimental effects of such distortions on the system and the connected equipment can result in significant damage and operational inefficiencies. However, the integration of a detuned filter reactor in the power system offers a practical solution to prevent the overloading of the capacitor and the associated equipment. By creating a high-impedance path for the harmonics to pass through the capacitor, the detuned filter reactor effectively blocks the flow of unwanted harmonics, thereby preventing damage to the system and equipment.

Figure 4. Capacitor

5. Working on the Detuned Filter Reactor

The working of this discussed system is simple and efficient. The windings in the detuned reactor produce inductive reactance which is proportional to the frequency of the harmonic currents generated. That is, the magnitude of the inductive reactance increases with the increase in the magnitude of the harmonics. This results in a high impedance factor for the harmonic currents to flow through it. The capacitive load of the power system when connected to this reactor is protected from the harmonic currents generated and the power system is undamaged. This method increases efficiency and improves the power factor of the power system.

6. Design Calculations

The design calculations for the Detuned reactors are as follows:

Current Drawn from Capacitor:

The formula to calculate current from a capacitor is: (VA*√3)/Phase Voltage

Current (in Amperes) = Apparent Power (in VA) / (Phase Voltage (in Volts) x √3)

Using the given values, we can substitute them into the formula: Current = (1000 VA x √3) / (440 V x √3)

Current = 1.31 A

The current drawn from the capacitor would be 1.31 A.

For the Stampings*: Drop Voltage*

= 440/(7%) * √3

The formula to calculate the voltage drop across a reactor with a given percentage impedance is:

Voltage Drop = (Percentage Impedance / 100) x Line Voltage x√3

Using the given values, we can substitute them into the formula: Voltage Drop = (7 / 100) x 440 x √3

Voltage Drop = 17.8 V

Therefore, the voltage drop across the reactor would be 17.8 V.

L = 2πf*L*I

=>2*3.14*50*1.31 = 17.8V

= 17.8 V / (2π x 50 x 1.31)

≈ 0.04327 H or 43.27 mH L = 43.27mH

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Using the formula for inductance in a reactor, $L = V / (2*\pi*f*I)$, $L = 17.8 / (2\pi \times 50 \times 1.31)$

$L \approx 0.04327$ H or 43.27 mH (millihenries)

Therefore, the inductance of the reactor would be approximately

43.27 mH

Core Stack

The formula for the apparent power in a reactor is:

Apparent Power (VA) = Voltage Drop (V) x Current (A) x √3 Using the given values, we can substitute them into the formula: Apparent Power = 17.8 x 1.31 x √3

Apparent Power ≈ 40.38 VA

Therefore, the core stack in the reactor would be approximately 40.38 VA.

Turns per Voltage

The formula for calculating turns per voltage in a reactor is: Turns per Voltage = Detuned Factor / Tongue Width

/ Stack Height

Using the given values, we can substitute them into the formula:

Turns per Voltage = 7 / (0.75 x 1) Turns per Voltage = 9.3 turns per volt

To find the total number of turns required for a voltage drop of 17.8 V, we can multiply the turns per volt by the voltage drop:

Total Turns = Turns per Voltage x Voltage Drop Total Turns = 9.3 turns per volt x 17.8

Total Turns ≈ 165.54 turns

Therefore, the required number of turns for a voltage drop of

17.8 V would be approximately 166 turns.

7. Hardware Specifications

The Table.1 Below shows the hardware specifications that are essential in devising the work.

Table 1. Hardware Specifications

DETAILS	VALUE
Number of turns	166 turns
Insulation material	Class F NOMEX
Bobbin	Epoxy
Current rating	1.31A
Voltage rating	17.8V
Voltage in the system	440V
Impedance value	17.8Ω
Inductance value	43.27mH
Core type	Type 16

8. Design Diagram

The Design diagram in Fig.5 below shows the front , top and the side view of the proposed design .

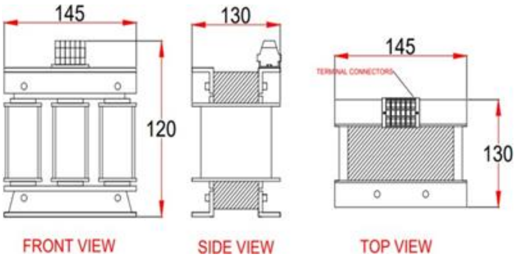

Figure 5. Design Diagram

9. Hardware Setup

The hardware setup for the Detuned Filter Reactor Setup is shown in the fig.6 below

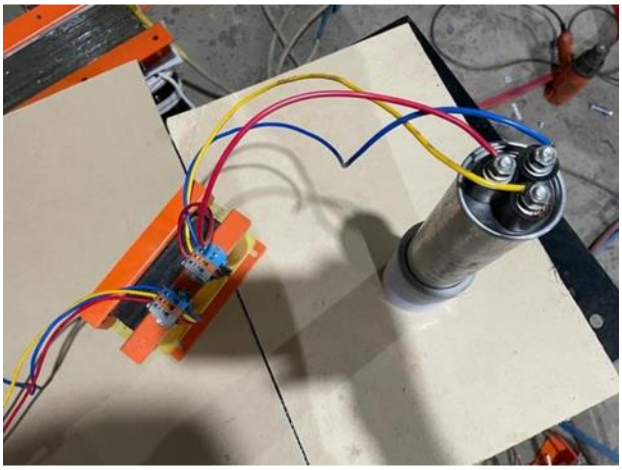

Figure 6. Detuned Filter Reactor Setup

10. Hardware Output

The Fig. 7 below depicts the output acquired from the power analyzer. This monitors the rate of electricity transferred , the electric power in the power analyzer is measured in watts-joules per second in S.I units.

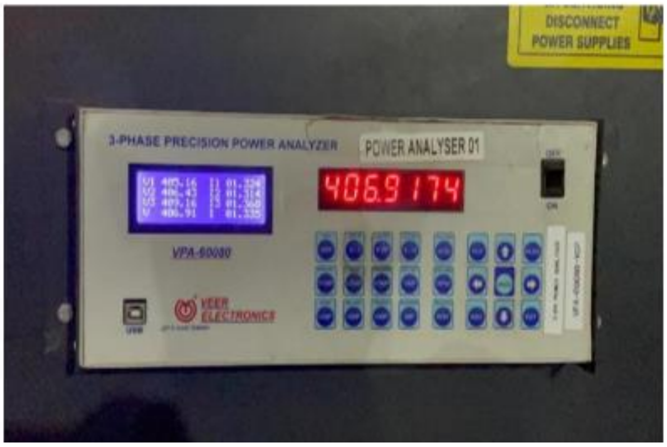

Figure 7. Output from Power Analyzer

11. Applications

- It is widely used in industrial applications like Variable frequency drives (VFDs) to control the speed of the motors which generates harmonic distortion that can cause a problem with other equipment in the same system.
- Detuned filter reactors are used in the reduction of the harmonic distortions caused by VFDs and improve the power quality.
- Used in welding equipment and in chemical plants in which large motors generate harmonic distortions. It reduces the risk of failure of the power system.
- Used in many commercial households like shopping malls, schools, and offices.

12. Advantages

- Ensures stability of systems with non-linear loads by preventing increases in harmonic current and voltage amplitudes.
- Mitigates the risk of heat and high current stresses on capacitors by limiting the flow of harmonic current through them, thus increasing their operational lifespan.
- Detuned reactors feature low inductance tolerance.
- Prevents the problems of heating and overcurrent on protection equipment, transformers, switchgear, bus bars and cables.
- Improves power factor in the harmonic-rich environment.

13. Conclusion

A detuned filter reactor is a more effective solution for harmonic distortion compared to traditional passive or active filters. It can be fine-tuned to target specific harmonic frequencies, and can also improve the power factor of the power system connected to it. The design and implementation of the detuned filter reactor vary according to the power systems and the specific requirements of the application. This proposed 1kVAR detuned filter reactor prevents the power system from damage with an overall efficiency of 91%. The efficiency of the detuned reactor can be improved in the future and can be made compact in its design.

14. Future Scope

The future scope of the detuned filter reactors is used for electric vehicle charging stations and sources of renewable energy stations like wind and solar. The proliferation of electric vehicles has led to increased demand for charging infrastructure. Detuned filter reactors can be used in the reduction of harmonic distortion and in the improvement of the power factor of electric vehicle charging stations, resulting in more efficient charging and reduced energy costs.

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