Total Harmonics Distortion Level Indicator for the Industry to Maintain Healthy Parameters of 3-Phase Supply

Somnath Murlidhar Lambe, Kailash Jagannath Karande

Punyashlok Ahilyadevi Holkar Solapur University, SKN'S College of Engineering, Pandharpur, India

[1]*Received: 03 October 2023; Accepted: 19 November 2023; Published: 21 November 2023*

ABSTRACT

Non-linear drives offer numerous advantages in the real world of automation processes. The utilization of a Variable Frequency Drive (VFD) allows for the control of motor speed, either increasing or decreasing it. Despite the evident benefits, there are inherent drawbacks, notably the destabilization of power due to the generation of harmonics infiltrating the power system. This results in a departure from the typical sine wave voltage to a more unpredictable waveform, a random waveform. This study delves into the repercussions of the increase in line voltage caused by harmonics on power supply quality, particularly examining the impact on a capacitor bank employed for power enhancement. The recommendation proposed in this research advises the observation of total harmonics distortion level indication. The harmonic current generated traverses through the capacitor, generating additional voltage that can compromise the integrity of the capacitor bank. The suggested remedy to circumvent this issue is to refrain from channeling harmonics through high-voltage-producing capacitors. This entails the use of a coil with a higher quality factor (Q), ensuring reduced active power loss in the coil. Experimental findings consistently demonstrate the persistence of harmonics in line voltage, yet the capacitors remain unaffected, thanks to the implementation of parallel resonance. This phenomenon poses a genuine challenge in electricity distribution networks, where expensive capacitor banks are susceptible to damage from harmonic generation. The Maharashtra State Electricity Distribution Company Limited (MSEDCL) team recommended the pursuit of methods to prevent harmonic generation, recognizing the live problem. Unfortunately, altering the magnetic poles of the motor—a potential solution—is impractical, making the manipulation of frequency through the VFD drive the more viable alternative.

Nature's inherent rule of trade-offs is evident in this context: gaining frequency control through VFD drives comes at the cost of harmonic side effects. In response, efforts have been directed toward mitigating these undesirable consequences of harmonic generation devices. This innovation represents a significant stride in reducing the adverse impact of harmonics on capacitor banks, thereby contributing to the overall improvement of power line quality.

Keywords: *Capacitor Overvoltage Protection; Quality Factor; Power ratings; odd Harmonics; Parallel Resonance*

INTRODUCTION

The identification of high benefits emphasizes the reactor coil's potential as an innovative and viable option for improving the protection and performance of PFC capacitors in industrial plants and power systems. By taking overvoltage and its associated dangers into account, the use of HTSRs in tuned filters and THD level indicators may contribute to more dependable and stable power system operation. A Variable Speed Drive (VSD) is a device used in the industrial sector to regulate the speed of an AC motor. The VSD shifts the phase of the fundamental voltage and current, resulting in a low displacement power factor (DPF). The displacement angle is close to 40°. The electricity utility does not accept the low DPF, which is cos (39°) = 0.765 lagging. A Power Factor Correction (PFC) capacitor should be placed to increase the power factor and provide voltage support. The PFC capacitor is frequently used as a harmonic filter as well. The VSD also generates harmonics and inserts them into the line voltage. Line voltage total harmonic distortion (THD) is fairly high, reaching around 27.15%, which may be unacceptable to the power utility. Increased line voltage suddenly affects the ratings of the PFC capacitor bank.

A 10 μF PFC capacitor is connected in a shunt with the VSD to reduce the reactive power need caused by the low DPF. The test system is depicted in Fig. 1 as a three-phase power supply coupled to a three-phase 0.5 hp AC motor.

---

[1] *How to cite the article:* Lambe S M, Karande K J (November, 2023); Total Harmonics Distortion Level Indicator for the Industry to Maintain Healthy Parameters of 3-Phase Supply; *International Journal of Advances in Engineering Research;* Vol 26, Issue 5; 1-10

Initially, the test system is run without the High-Temperature Superconducting Reactor (HTSR) adjusted filter. Variable Speed Drive (VSD) introduces harmonics into the power supply. The three-phase balanced source voltage V_s. has a fundamental frequency of 50 Hz and has no harmonic voltages. When the PFC capacitor Cf is connected in parallel with the source impedance Zs, it can resonate at the natural frequency f_n which is determined by equation 1.

$$f_n = \frac{1}{2\pi}\sqrt{\frac{1}{L_s C_f} - \left(\frac{R_s}{L_s}\right)^2} \qquad \text{---------(1)}$$

Here, Ls is the equivalent inductance of the reactor inductor (Lf) and transformer secondary inductance value. These two inductances are in parallel. Rs is the internal resistance of the reactor. The resonant frequency fn is determined by the values of Ls and Cf. If any harmonic frequency in the system is equal to fn, it will create a high impedance (close to infinity) in the parallel circuit. As a result, even a small harmonic current can lead to a significant overvoltage across the PFC capacitor, which could be detrimental to its operation and integrity. To solve such high voltage issues due to harmonics insertion and prevent overvoltage, a reactor (Lf) is connected in series with the PFC capacitor (Cf) with the THD level indicator. The reactor's internal resistance is denoted by Rf. By tuning the reactor's inductance (Lf) to the harmonic frequency (ωh), which corresponds to the unwanted harmonic frequencies in the system, the parallel resonance is made to stop these harmonics. The value of the reactor inductance (Lf) can be calculated using equation (2). The introduction of the reactor in series with the PFC capacitor helps to control the impedance at the harmonic frequencies, preventing overvoltage across the capacitor and ensuring stable and efficient operation of the power factor correction system, this THD level indicator gives alerts for upper crossing limit. This arrangement allows for effective harmonic filtering while protecting the PFC capacitor from harmful resonant conditions.

$$L_f = \frac{1}{\omega_h^2 C_f} \qquad \text{-----------(2)}$$

BACKGROUND

PFC capacitors are commonly used in industrial plants to improve the power factor and support voltage in electrical systems. However, it is critical to be mindful of the potential hazards connected with these capacitors, particularly in overvoltage situations. Overvoltage in a PFC capacitor can cause failure and, in extreme situations, explosion. PFC capacitor failure in real-world circumstances has been recorded multiple times [1–2]. The causes of these failures can range from switching events to malfunctions. Voltage transients and overvoltage can be caused by rapid switching activities, such as turning on or off the PFC capacitors. Furthermore, power supply breakdowns might create unexpected voltage spikes that may exceed the capacitor's rating.

Problems with the capacitor bank switching control board are another cause of capacitor bank spoilage. Control system problems that handle the switching of capacitor banks can cause erroneous switching and contribute to overvoltage situations. Between the PFC capacitor and the system line inductance, series resonance can occur. At the resonant frequency, the capacitor's impedance and inductance become extremely low, resulting in strong circulating currents and excessive voltages across the capacitor. It is critical to follow the following procedures to avoid capacitor failure and explosions produced by excessive voltage.

1. Proper Switching Control: To avoid abrupt voltage changes, ensure that the switching of PFC capacitor banks is well-coordinated and managed.
2. Monitoring and Protection: Install monitoring and protection systems to identify overvoltage and respond properly, such as unplugging the capacitor bank during fault events.
3. Detuning Reactors: Connect detuning reactors in series with PFC capacitors to minimize parallel resonance and shift the resonant frequency away from the working frequency range.
4. Plan for contingencies and evaluate the capacitor's ability to endure potential overvoltage conditions by taking continuous overload limits into account. [3]- [4].

Industrial plants can ensure the safe and effective functioning of their power systems by recognizing the potential reasons for PFC capacitor failures and implementing suitable precautionary measures. This contributes to a better power factor and steady voltage support. The publications [5–6] emphasize parallel resonance as the primary cause of power factor correction (PFC) capacitor failures. Parallel resonance arises as a result of the constantly changing system impedance generated by switching lines, reactors, and shifting loads in and out of the system. Harmonics can be produced by power electronics loads such as rectifiers, variable frequency drives, and adjustable speed drives, resulting in poor power quality. The voltage across the capacitor can increase and trip or explode if the line impedance resonates with the PFC capacitor and an injected harmonic current matches the resonant frequency. A hybrid anti-resonance system that uses passive-tuned filters to move the parallel resonant frequency away from the frequency of the injected harmonic is suggested in [7] as a solution to this problem. A series reactor can be added in addition to the current PFC capacitor to create passive-tuned filters. However, the resistance of the reactor is determined by its quality factor (Q), which results in power losses. Better reactor quality and lesser losses are indicated by a higher Q value. Higher Q values may be hard to find and more expensive, while reactors with Q values between 40 and 100 are often accessible on the market. In the works [8], a good-quality factor reactor is proposed as a potential remedy. The used coil's Q factor is less than 500. Filter coils are capable of reaching exceptionally high Q values and have nearly no resistance. Low power losses, improved tuned filter performance, and efficient shifting of the parallel resonance frequency away from the injected harmonic frequency are just a few advantages of using a high Q factor coil in tuned filters. While low Q factor coils have been created, and their characteristics are discussed in [8] through [9], [10] proposes that a cryogenic cooling system is necessary to control the working temperature of such coils. This is because their superconducting qualities must be maintained at low temperatures. Notably, the use of High Q-tuned superconducting reactors (HTSR) with tuned filters for the protection of PFC capacitors appears to be a novel concept with no articles on this particular application having been published in the literature. Overall, using HTSRs as a component of a tuned filter offers a promising potential remedy to stop PFC capacitor failures brought on by parallel resonance and can enhance the stability and dependability of the power system. In order to safeguard Power Factor Correction (PFC) capacitors from overvoltage problems brought on by harmonics and system resonance, the study [11] under review examines the benefits of utilizing High-Temperature Superconducting Reactors (HTSRs) in passive-tuned filters. They only used the results of the simulation and a filter coil with a Q factor of 1000. This paper's main contribution is the recognition that adding HTSRs to passive-tuned filters can provide significant advantages in a number of areas, such as:

Lower Losses: When compared to conventional reactors with resistive elements, HTSRs have essentially little resistance, which considerably lowers power losses in the tuned filter.

Stronger Filtering: The high-quality factor (Q) of HTSRs enables stronger harmonic and other undesired frequency filtering, enhancing the system's power quality.

Overvoltage Mitigation: The research shows that overvoltage in PFC capacitors can be effectively mitigated by using HTSRs in tuned filters, lowering the risk of failures or explosions brought on by excessive voltage circumstances.

SYSTEM ARCHITECTURE

System Working

A system based on a PIC microcontroller is utilized to identify the rms voltages of fundamental components, 3rd, 5th, and 7th harmonics. Detection involves utilizing the secondary inductance of the transformer along with additional L and C values to create parallel resonance for the specified harmonics. The fundamental component undergoes rectification, and the output is directed to a filter capacitor, then to a scaled potentiometer, with 1/4th of the signal supplied to the microcontroller. Calibration occurs during programming, employing Equation 2 to calculate parallel resonance for the 3rd, 5th, and 7th harmonics.

For the 3rd component (150Hz), C= 5 μF and L= 198 mH are used;
For the 5th component (250Hz), C= 4 μF and L= 99 mH are used;
For the 7th component (350Hz), C= 3 μF and L= 66 mH are used.

These calculations are based on a standard 1 μF capacitor and 22 mH inductor. The resonated components then pass through rectifier circuits constructed with Schottky diodes to minimize the forward voltage drop (0.2 volts per diode). The rectified output is fed into a 100 μF filter capacitor, and 1/4th of this output is directed to the microcontroller. Calibration in programming adjusts the reading, factoring in the bridge rectifier's diodes and the transformer turns ratio of 12, resulting in a displayed 4.8-volt rms value on the LCD display board.

Theoretical and practical calculations indicate a 95% accuracy in determining the rms value of each harmonic, which is then indicated on the LCD board. If any harmonics surpass a critical limit, a precalculated parallel resonance coil is connected in series with the Power Factor Correction (PFC) capacitor, creating a total parallel resonance (as depicted in Figure 1). This method prevents high rms value harmonics in the line voltage, prohibiting their passage through the capacitor. The PFC capacitor, responsible for power factor correction, is thus shielded from harmonics generated by a nonlinear drive, such as a Variable Frequency Drive (VFD), using a high Q filter coil. Figure 1 illustrates an equivalent circuit diagram of harmonic current introduced by a nonlinear drive, with Rs representing the internal resistance of the transformer secondary and R_f signifying the resistance of the inductance coil used for filtration.

(IJAER) 2023, Vol. No. 26, Issue No. V, November **e-ISSN: 2231-5152, p-ISSN: 2454-1796**

L (equivalent) = (Ls * Lf) / (Lf+Ls)
Ls = Transformer secondary inductance value
Lf = Resonated coil to be connected.
Cf = Phase to neutral PFC capacitor value

Figure 2 illustrates a unit presenting readings for fundamental components, with the fundamental component measured at 230 volts. In Figure 3, the unit displays readings for the 3rd harmonics, which have an rms value of 6.9 volts. Similarly, Figure 4 shows readings for the 5th harmonics, with an rms value of 2.3 volts. Figure 5 displays readings for the 7th harmonics, indicating an rms value of 0 volts. Figure 6 showcases the unit displaying the total harmonic distortion (THD) level. All these readings cycle every 1 second. The THD is determined using the following formula.

$$THD = \sqrt{(V3)^2 + (V5)^2 + (V7)^2} \; / \; VFundamental \quad \text{-----} \ (3)$$

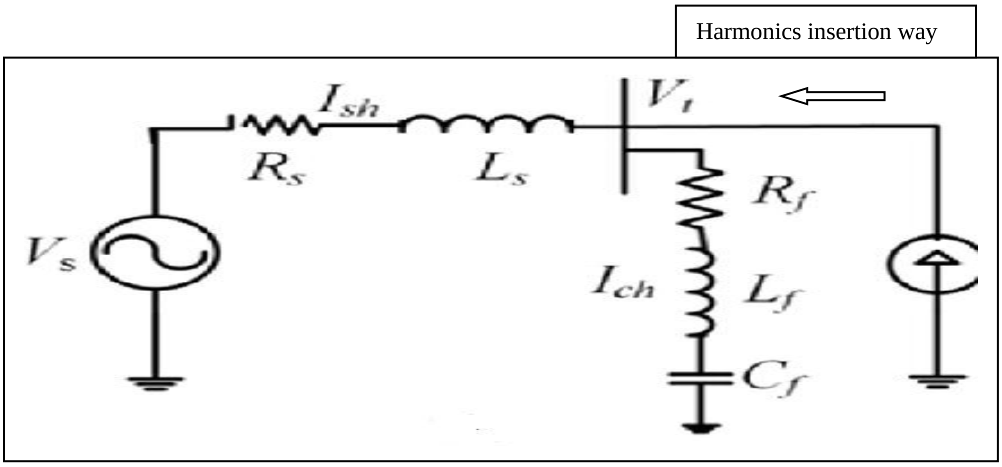

Fig. 1 Circuit diagram indicating the way of harmonics insertion

RESULTS

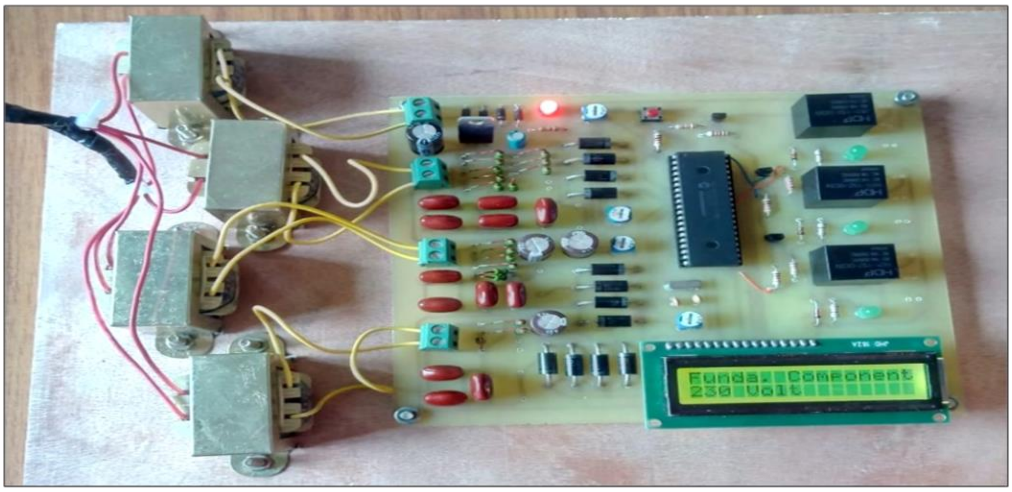

Fig. 2 Fundamental component rms value

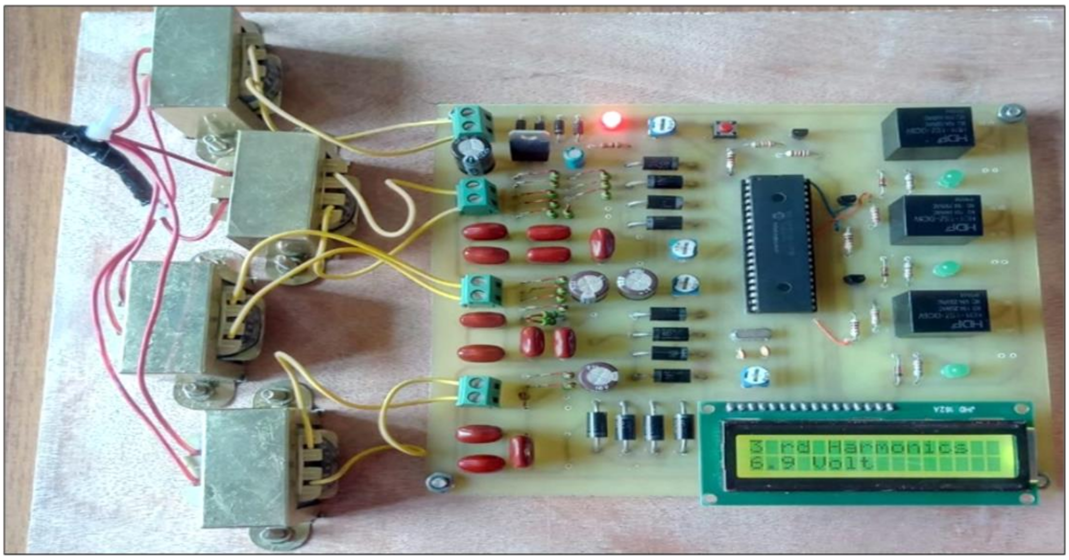

Fig. 3 Reading of 3rd harmonics

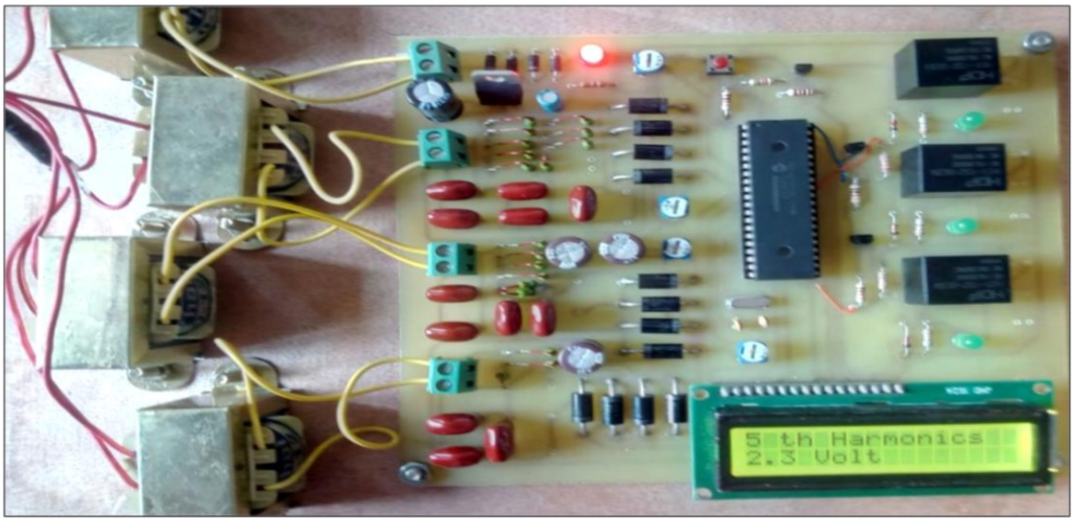

Fig. 4 Reading of 5th harmonics

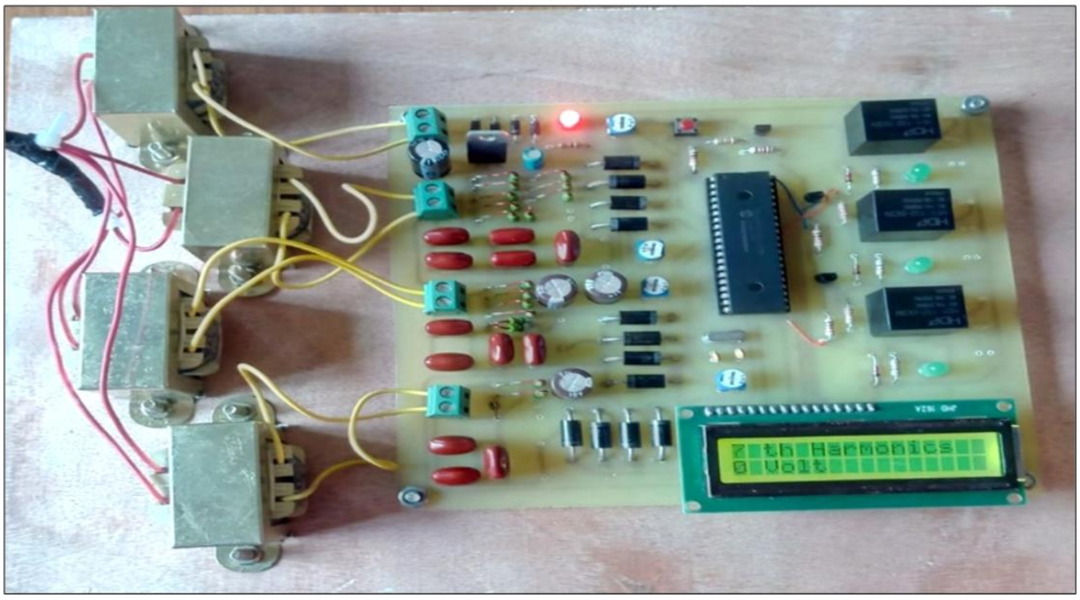

Fig. 5 Reading of 7th harmonics

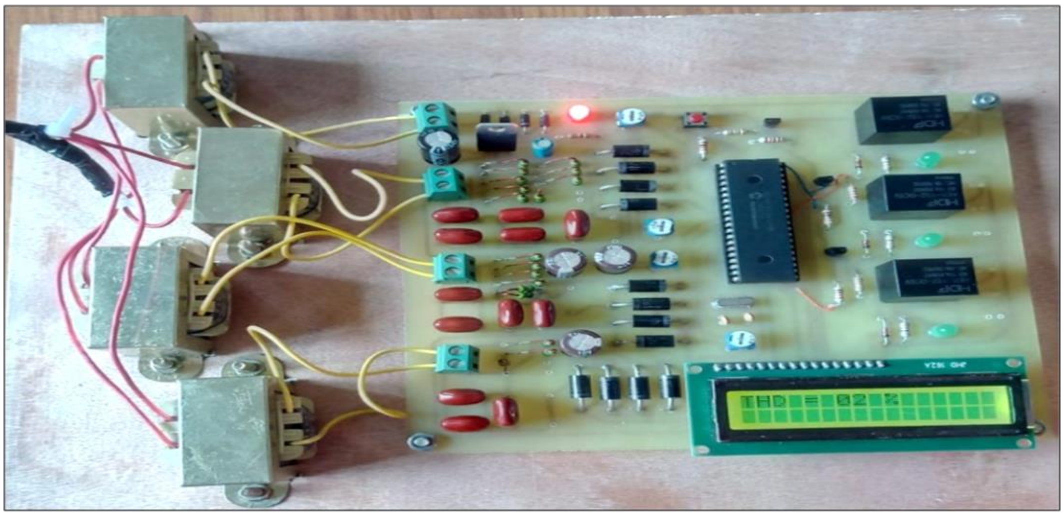

Fig. 6 Reading of THD level

Figure 7 shows the experimental setup to detect harmonics readings when the VFD drive is bypassed and a direct 3-phase supply is given to load. Figure 8 shows 3rd harmonics reading of 1.455 volt. Figure 9 shows the 5th harmonics reading of 0.763 volts. Figure 10 shows 7th harmonics reading of 0.473 volts.

Figure 11 shows the experimental setup to detect harmonics readings when the VFD drive is activated and supply is given through the VFD drive to load. Figure 12 shows 3rd harmonics reading of 1.916 volt. Figure 13 shows 5th harmonics reading of 1.466 volts. Figure 14 shows 7th harmonics reading of 1.312 volts. All these readings indicate that as the VFD drive is activated rms value of harmonics increases. All these affect distortion at the THD level. All these readings are summarized in below Table No. 1

Table no.1 VFD bypassed and through VFD readings of harmonics

Sr. No	Harmonics No.	VFD bypassed	Through VFD	Observation
1	3rd	1.455V	1.916V	RMS value of 3rd harmonics increased
2	5th	0.763V	1.466V	RMS value of 5th harmonics increased
3	7th	0.473V	1.312V	RMS value of 7th harmonics increased

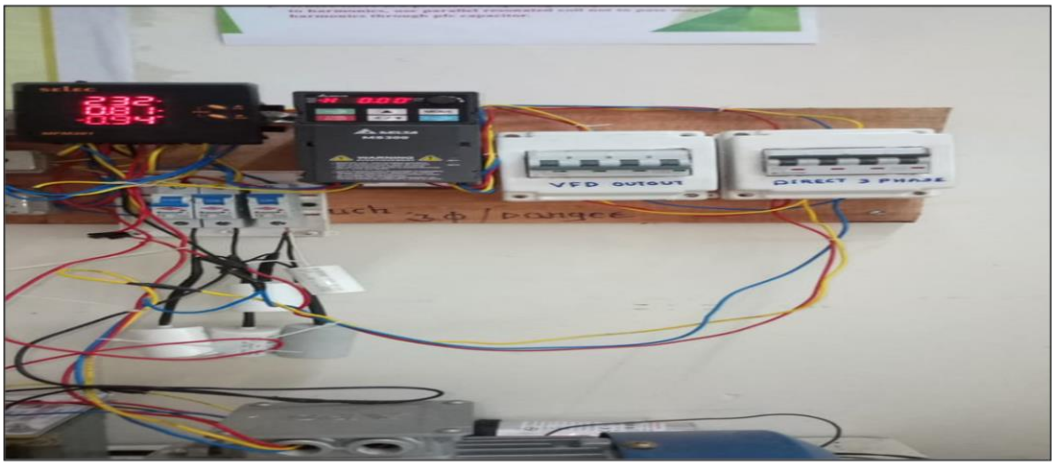

Fig. 7 Direct online 3 Phase harmonics indication

Fig. 8 Direct online 3rd harmonics reading

Fig. 9 Direct online 5th harmonics reading

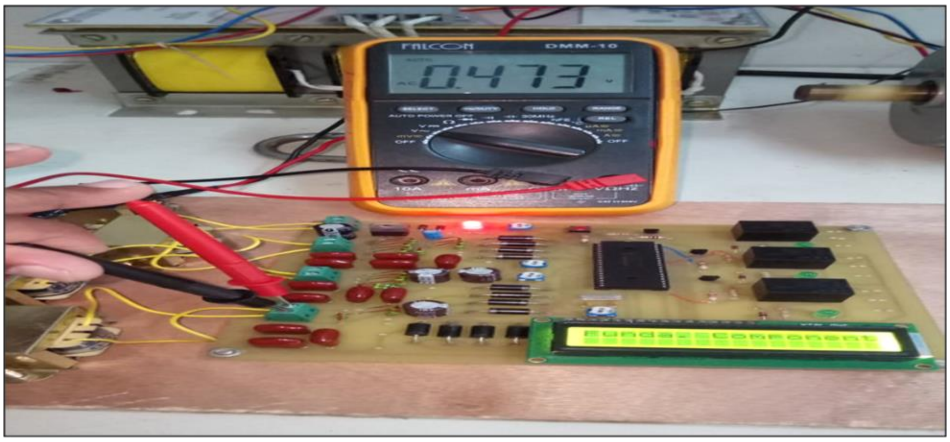

Fig. 10 Direct online 7th harmonics reading

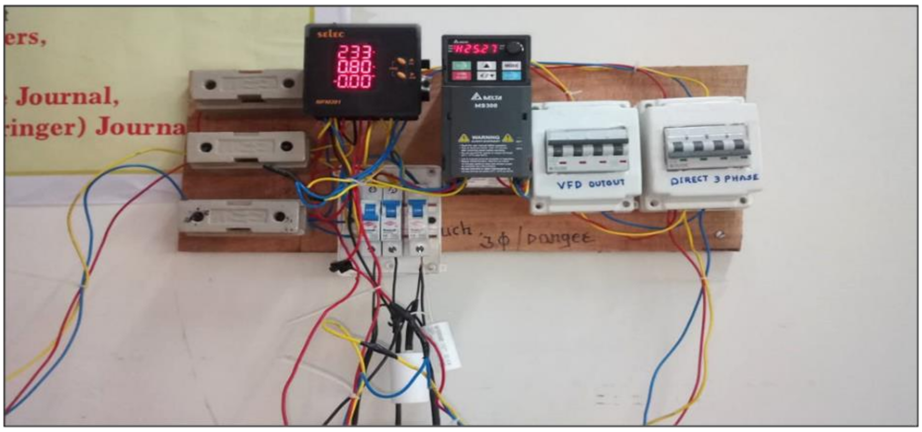

Fig. 11 VFD activated harmonics indication

Fig. 12 VFD activated 3rd harmonics reading

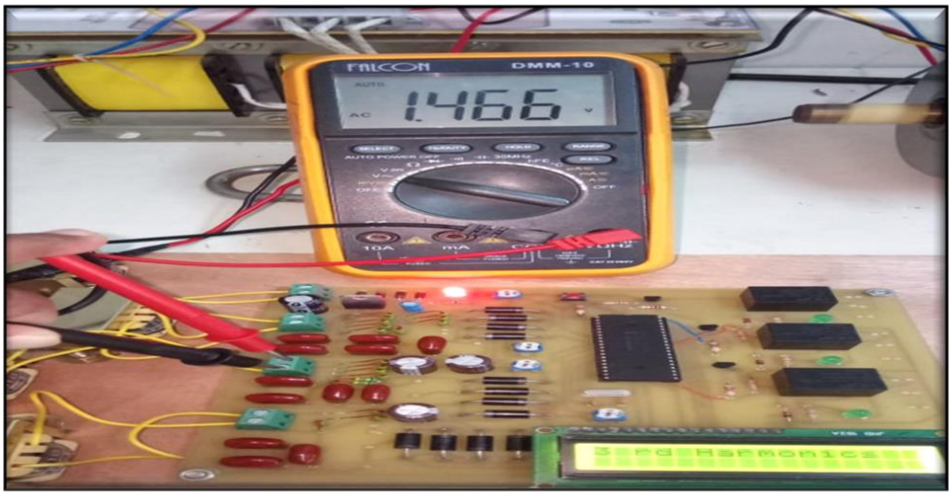

Fig. 13 VFD activated 5th harmonics reading

Fig. 14 VFD activated 7th harmonics reading

ACKNOWLEDGMENT

The authors express their gratitude to the Management of SKNCOE, Pandharpur, for generously providing a Basic Electrical Lab, facilitating the installation of an Experimental setup, 3-phase electrical connection, and other essential facilities for the experimentation. Special appreciation is extended to Deshpande Sir, the head of the Power

House at Sinhagad College of Engineering, Pandharpur, for his invaluable assistance in addressing every minor factor related to the power factor. His guidance included insights into the number of KVA transformers at Sinhagad, the quantity of KVAR reactive loads, and the monthly benefits derived. The authors also acknowledge with thanks the commercial provider who supplied a customized 1 KVA isolation transformer, VFD drive, and 1 HP, 3-phase motor from Pune. Lastly, sincere appreciation is extended to Mrs. Lamkane Madam, the Executive Engineer from the testing department, and the team from MSEDCL Solapur, who visited the research lab to verify and validate the obtained results. Their involvement adds credibility to the research findings.

CONCLUSIONS

Although VFD drives have many advantages, they also have some disadvantages. We are not saying don't use VFD drives, but don't ignore the side effects of VFD drives if used in higher KVA ratings. The fact that harmonic generation is causing bad effects cannot be ignored. A team of officials from MSCDCL who came to visit said that customers whose THD level is more than 3% are penalized heavily. They damage the entire electricity distribution network. As the THD level increases, the sine wave voltage becomes random and has an adverse effect on the load. From all these side effects it can be observed that harmonics generation should be very less. Much less than a limit. From the above research, it can be said that where there is a problem of capacitor bank spoil, a high-quality factor Q a resonated coil must be used in a parallel resonance way. Using these coils will increase the life of the capacitor banks and will also keep the distribution network in good condition. THD is a key indicator of the quality of electrical power. Monitoring THD levels helps in assessing the cleanliness and stability of the power supply in electrical systems. High THD levels can adversely affect the performance and efficiency of electrical equipment, particularly in sensitive devices such as computers, medical equipment, and communication systems. Observing THD levels is essential to ensure the proper functioning of such equipment. Elevated THD levels can result in energy losses and reduced efficiency in power distribution systems. By observing and managing THD, it is possible to optimize energy consumption and enhance overall system efficiency. Many electrical standards and regulations set limits on THD levels to ensure the quality and safety of electrical power. Observing THD levels helps in confirming compliance with these standards. Excessive harmonics can lead to overheating and premature failure of electrical components. Monitoring THD levels allows for early detection of potential issues, preventing damage to equipment and reducing maintenance costs. THD levels are closely related to power factor issues. Observing THD assists in identifying areas where power factor correction measures may be needed to enhance the overall efficiency of power systems. High THD levels necessitate the implementation of harmonic filtering solutions. By observing THD, we can identify the specific harmonics causing issues and implement targeted mitigation strategies. In large-scale power distribution networks, excessive harmonics can impact grid stability. Monitoring THD levels helps grid operators maintain a stable and reliable power supply.

REFERENCE

[1] M. Kutija and Luca Pravika, "Effect of Harmonics on Ferroresonance in Low Voltage Power Factor Correction System—A Case Study," Applied Science, vol. 4322, no. 11, 2021.

[2] M. N. Zaidi and Adlan Ali, "Power Factor Improvement Using Automatic Power Factor Compensation (APFC) Device for Medical Industries in Malaysia," in MATEC Web of Conferences, 2017.

[3] K. Dai, Xinwen Chen, and Li Peng, "Parallel resonance detection and selective compensation control for SAPF with square-wave current active injection," IEEE Transactions on industrial Electronics, vol. 64, no. 10, pp. 8066-8078, Oct. 2017.

[4] Y. W. Li, Ruiqi Wang, and Chenghui Zhang, "Analysis and mitigation of resonance propagation in grid-connected and islanding microgrids," IEEE Trans. Energy Convers, vol. 30, no. 1, pp. 70-80, March 2015.

[5] X.Wang, M. Liserre, and F. Blaabjerg, "A review of passive power filters for three-phase grid-connected voltage source converters," IEEE J. Emerg. Sel. Topics Power Electron, vol. 4, no. 1, pp. 54-68, 2016.

[6] N.Vilhena, P. Arsenio and A. Pronto, "Preliminary design and test of low-resistance high-temperature superconducting short-circuited," IEEE Trans. Appl. Supercond, vol. 28, no. 4, 2018.

[7] V. Khokhlov, Friedemann Möller, and Jan Meyer, "Adverse Impact of Harmonic and Interharmonic Supply Voltage Distortion on Mass-Market Electrical Appliances," IEEE Open Access Journal of Power and Energy, vol. 10, pp. 395-405, January 2023.

[8] T. Dao and Bao Toan Phung, "Effects of voltage harmonic on losses and temperature rise in distribution transformers," IET Journal, vol. 12, no. 2, pp. 347-355, August 2017.

[9] H. G. Beleiu, Sorin G. Pavel and IulianM.T.Birou, "Effects of voltage unbalance and harmonics on drive

(IJAER) 2023, Vol. No. 26, Issue No. V, November **e-ISSN: 2231-5152, p-ISSN: 2454-1796**

systems with induction motor," Journal of Taibah University for Science, vol. 16, no. 1, pp. 381-391, April 2022.

[10] N. X. Cuong and DO Nhu, "Influence of Harmonics on the Working Efficiency of a 6/1.2 kV Transformer in a Pit Mine," Journal of the Polish Mineral Engineering Society, vol. 1, no. 2, pp. 149-159, 2021.

[11] M. S. Vora and Mr. Dipak Bhatt, "A Comprehensive Review of Harmonics Effects on Electrical Power Quality," INTERNATIONAL JOURNAL OF ENGINEERING DEVELOPMENT AND RESEARCH, vol. 2, no. 1, pp. 15-25, 2019.