MINIMIZE THD FOR THREE PHASE AC-DC CONVERTER USING SWITCHING CAPACITOR TECHNIQUE

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ABSTRACT: The increasing demand for high-efficiency and power-quality improvement in AC-DC converters necessitates advanced techniques to minimize Total Harmonic Distortion (THD). This research focuses on the implementation of a Switching Capacitor Technique (SCT) to optimize the performance of a three-phase AC-DC converter by effectively reducing THD. The proposed method leverages controlled capacitor switching to shape the input current waveform, thereby improving power factor and reducing harmonic distortion without the need for complex active filtering. A comparative analysis with conventional PWM-based rectifiers and passive filtering techniques demonstrates the effectiveness of the SCT approach in achieving lower THD, higher efficiency, and improved voltage regulation. The system is designed and simulated in MATLAB/Simulink, and the results validate the significant reduction in harmonic content while maintaining stable output voltage. The findings suggest that the proposed technique can be a cost-effective and efficient solution for industrial applications requiring high power quality.

KEYWORDS: Full-bridge converters, Input current shaping, low-distortion input current, single-stage power factor correctors (PFCs)

1. INTRODUCTION

A modern technological era has grown and developed as a result of the inexplicable changes that have occurred in the automated world of today [1]. It is now essential for electric utilities to make the required adjustments in order to meet the demands of the expanding application needs [2, 3]. As a result, power electronic interfaces are now absolutely necessary to achieve the goal. The acrimonious signals are unintentionally produced by the ensuing widespread use of semi-conductor power switches. It might have a negative impact on the system's functionality and performance. Over 70% of the electrical energy produced today passes through power electronic systems, and this percentage is predicted to rise to 100% in the future [4, 5].

Large high voltage direct current transmission systems and small converters are just two of the many uses for three-phase AC-DC converters. Among their many uses are controlled power supplies, traction equipment, various motor drive types, electrochemical processes, and many more [6, 7]. They fall into two major categories from the perspective of the commutation process: force-commutated pulse width modulated converters and line-commutated controlled converters [8]. The majority of power electronic applications use an electric utility-provided 50 or 60 Hz sine wave ac voltage that is first converted to a dc voltage as the power input. Increasingly, the trend is to use the inexpensive rectifiers with diodes to convert the input ac into dc in a uncontrolled manner, using rectifiers with diodes as illustrated by the block diagram in Figure 1 [9].

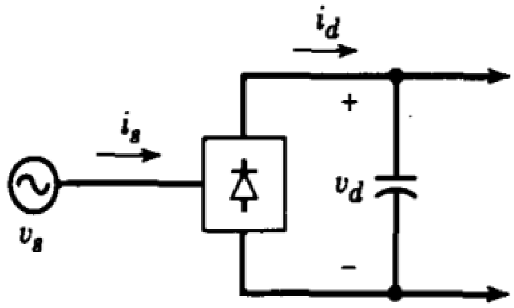

Figure 1: Block diagram of a rectifier

A rectifier is an electronic circuit that converts alternating current (AC) into direct current (DC). The block diagram of a rectifier typically consists of four main components: the AC input source, which provides the AC voltage; diodes, which allow current to flow in only one direction, converting the AC to pulsating DC; a filter, which smooths out the fluctuations or ripples in the DC signal; and the DC output, which delivers the final converted, smooth DC voltage. Depending on the rectifier type (e.g., half-wave, full-wave, or bridge), the arrangement and number of diodes may vary. This circuit is commonly used in power supplies for converting AC to DC for powering electronic devices.
A rectifier's dc yield voltage ought to be as wave-free as feasible. Consequently, a massive capacitor is connected to the dc side as a channel. This capacitor is charged to a level that is nearly equal to the maximum input voltage of the climate control system. Because of this, the current flowing through the rectifier is quite large close to the 50Hz cooling input voltage's peak and does not flow continuously; instead, it reaches zero for limited ranges during each half-cycle of the line repeat [7]. Extremely distorted current is drawn from the utility by these rectifiers. The percentage of current winding permitted into the utility will eventually be capped by consistent standards and regulations, and basic diode rectifiers might not be allowed.

2. PULSE WIDTH MODULATION

PWM stands as a commonplace power electronic technique to control power converter outputs specifically for the implementation of AC-DC converters. .clock signals to control load power based on changing pulse durations which form part of periodic signals. The Three-Phase AC-DC converter implements PWM technology to transfer alternating grid current into direct current through its operation. Total Harmonic Distortion known as THD occurs during conversion that affects the DC output quality and creates unnecessary system inefficiency and noise.

The Switching Capacitor Technique operates to reduce THD in power conversion systems by enabling improvement of power quality output. The harmonic content of outlet waveforms becomes lower through the addition of capacitors alongside switching elements that control the converter timing operations. The conversion efficiency and operating voltage of the converter improve when the switching capacitors are precisely controlled leading to a less distorted DC output. Through combination of PWM with Switching Capacitor Technique in

Three-Phase AC-DC converters users can achieve optimal modulation strategies. High THD reduction creates enhanced power quality along with increased efficiency for the converter system. Such control method brings extraordinary value to applications needing precise output with reduced distortions therefore serving industrial motor drives and power supplies as well as renewable energy implementation.

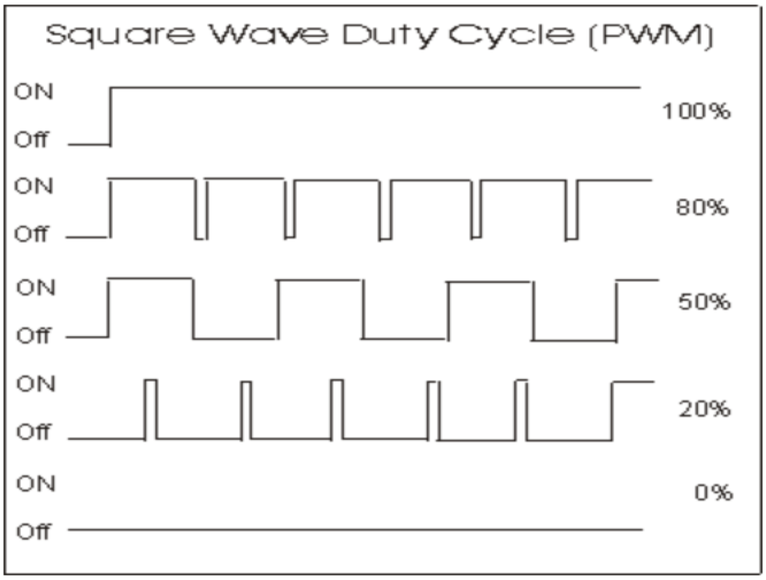

Figure 2: Pulse Width Modulation

3. AC-DC CONVERTER

An AC-DC converter operates as a power electronic device which converts alternating current (AC) from the grid structure into direct current (DC). The Three-Phase AC-DC Converter accepts three-phase AC power input to produce output DC power which supports industrial drives and power supplies and renewable energy applications. The generation of Total Harmonic Distortion (THD) represents a main difficulty for such converters because it leads to power quality degradation and waste of energy along with unwanted system noise.

THD reduction in converters depends on implementing the Switching Capacitor Technique during design. The converter circuit receives capacitors combined with switching devices through this method for control of the conversion process timing. The converter achieves operation optimization through timed capacitor swaps that decreases harmonic content in the output DC voltage. During the conversion process this technique provides harmonic frequency smoothing and reduction of undesirable harmonics by stabilizing the switching operation fluctuations.

A system based on switching capacitors transforms component phase connections to reach harmonic frequency reduction along with cancellation. This technique reduces the THD values through its ability to enhance power balance and regulate voltage conditions which leads to improved output DC quality. Through this technique the performance of Three-Phase AC-DC converters reaches higher levels which produces more efficient systems with reduced

IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876
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power losses and better reliability. Three-Phase AC-DC converters benefit from this method because it generates low-distorted DC power suitable for operation sensitive equipment.

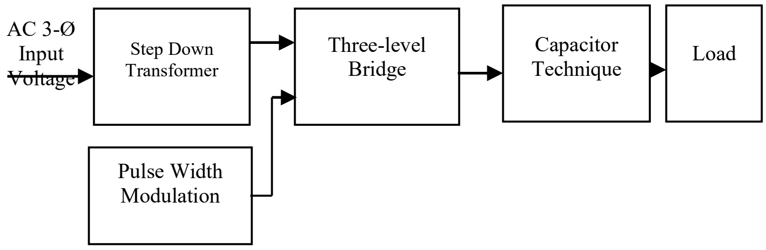

Figure 3: Block Diagram of Proposed AC-DC Convert

The implementation of the proposed AC-DC converter consists of major components that perform efficient power conversion tasks and minimize THD levels. The starting component receives a three-phase alternating current through the AC Input. The Rectifier Circuit receives AC power from the input to transform it into pulsating DC electricity using diodes or thyristors. After the rectification process the Switching Capacitor Network launches to reduce Total Harmonic Distortion (THD). An array of capacitors plus controlled switches operates to minimize DC output harmonic signals through smooth voltage processing. The converter receives input from switching capacitors to regulate its operation by refining the voltage and current waveforms thus achieving better DC signal quality while minimizing ripple. The Filter receives the output from the switching capacitor network to finalize the smoothing process before the remaining ripples. The final stage delivers a smooth direct current output ready for different uses. A Controller run by the system maintains both optimal performance and voltage control levels.

4. PROPOSED MODEL

The design of the proposed model with Switching Capacitor Technique for Three-Phase AC-DC Converter aims to minimize Total Harmonic Distortion (THD) for boosting power quality alongside efficiency enhancement in power conversion. The converter circuit first performs rectification on the three-phase alternating current that originates from the grid. The processed signal from rectification goes through a network comprising switching capacitors before output. A set of capacitors and controlled switches form this network which enables users to modify conversion times together with phase operations through strategic control methods. The system distribution of specific capacitor timing periods allows the system to suppress harmonic frequencies and develop a smooth DC output. The capacitors function as harmonic correctors during rectification whereby their neutralizing effect creates a balanced and stable voltage output. A filtering mechanism works within the converter to complete the process of removing all ripple from the DC signal before producing the output voltage. The central controller tracks capacitor operation through its control mechanism to enable maximum performance of the system. The system through this approach lowers THD while enhancing power quality and achieves higher efficiency and operational performance in Three-Phase AC-DC converters suitable for applications needing pure DC power without substantial distortion.

IJFANS International Journal of Food And Nutritional Sciences
Official Publication of International Association of Food and Nutrition Scientists

ISSN PRINT 2319 1775 Online 2320 7876
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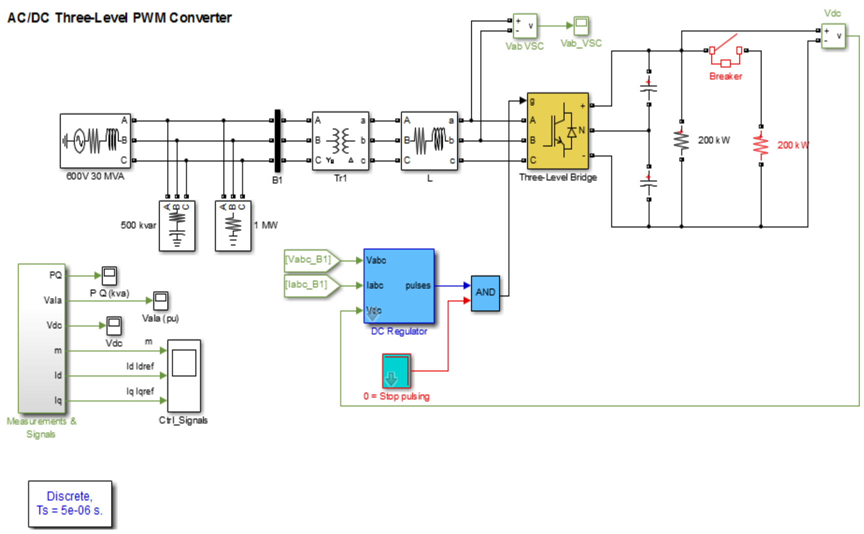

Figure 3: MATLAB Simulink Model of AC/DC Three Level PWM Converter

Description:-

- Converter rating: 500 Volts DC, 500 kW
- AC Supply: three-phase, 600 V, 30 MVA, 60 Hz system
- Voltage-sourced Converter (VSC): - Three-level, three-phase IGBT bridge (modeled using the "Three-Level Bridge" block) controlled by a PWM modulator (carrier frequency of 1620 Hz) - DC Link: 2 capacitors of 75000 uF
- Controller: The DC regulator uses two PI regulators to control the DC voltage while maintaining a unity input power factor for the AC supply.

Switching Capacitor Technique

Figure 4 illustrates the circuit's components, which include sinusoidal mains voltage Vin, four switches (S1, S2, S3, and S4), coupled inductors Np and Ns, diodes Da, Db, De, Dd, D1, D2, D3, and D4, two capacitors (C and C2), two secondary diodes (D5 and D6), output diode Do, output capacitor Co, and load Ro. The coupled inductor n has a turn ratio of Ns Np. To prevent any two switches from the same leg from conducting simultaneously, a known delay is added between turning off one switch and turning on the other switch on the same leg. Both legs' gate drives—S"S4 or S2, S3—complement each other.

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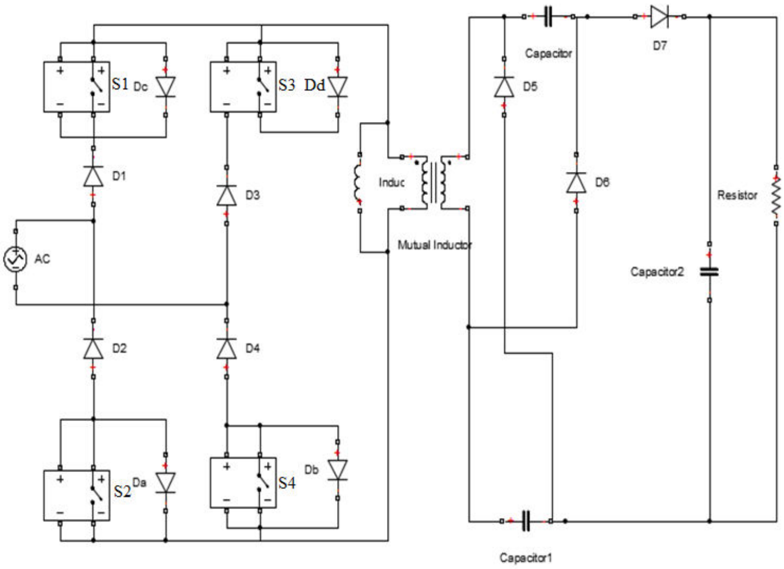

Figure 4: Circuit of Proposed Converter using Switching Capacitor Technique

The utilization of switches with low obstruction RDS (ON) is to diminish the conduction loss of the whole circuit. The equal charged current isn't inflow. The proposed converter used the idea of exchanged capacitor procedure ie, two capacitors can be charged in equal and released in arrangement to accomplish a high advance up gain. In this manner, capacitors on the optional sides CI and C2 are charged in equal and are released in arrangement by the switches are killed and turned ON is appeared in Figure 4. Obligation cycle D is characterized as when SI and S2 are both ON during the principal half cycle or when S3 and S4 are both ON during the subsequent half cycle. The rule is that, when the switches are turned ON, the vitality put away in attractive inductor and the coupled-inductor-instigated voltage on the auxiliary and the initiated voltage makes VL2, Vc" and VC2 discharge vitality to the yield in arrangement.

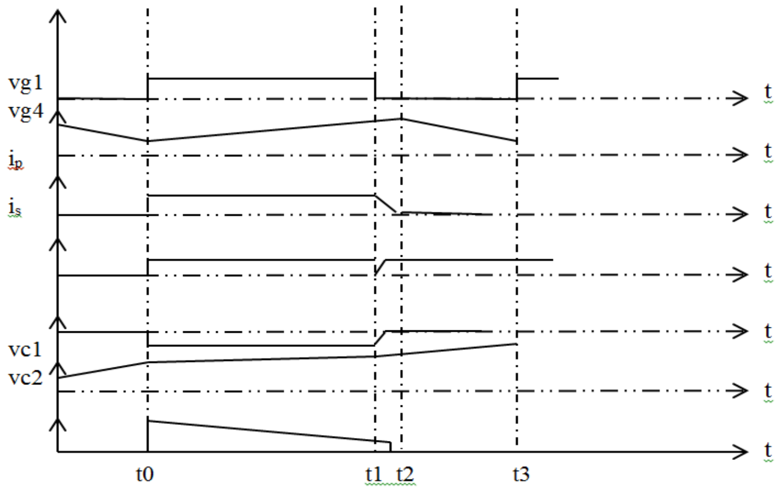

Figure 5: Waveforms of AC-DC Converter using Switching Technique

Multiple stages define the waveforms of AC-DC converter devices using Switching Capacitor Technique including AC Input and Rectified Output and Smoothed DC Output. There are three sinusoidal voltage phases in the AC Input and each phase differs from others by 120-degrees. The Rectified Output generates pulsating DC after rectification but remains marked by both substantial ripple and significant harmonic distortion. The Smoothed DC Output results from the application of the Switching Capacitor Technique upon this pulsating output. By scheduling capacitor changes according to pre-determined intervals the harmonic frequencies can be eliminated which decreases voltage distortions while enhancing the quality of the waveforms. The Smoothed DC Output delivers a very pure and stable DC waveform because it contains low Total Harmonic Distortion (THD) levels suitable for critical electrical devices.

Mode of operation

An AC-DC converter operating with Switching Capacitor Technique follows these essential steps during its process. At the first stage the rectifier receives AC Input to produce a pulsating DC signal from three-phase alternating current. The signal output from the rectifier maintains both harmonic and ripple content. The Switching Capacitor Network becomes operational and modulates the conversion process timing through the execution of capacitor and switch controls. A network of capacitors controls pulsating DC output by limiting harmonic distortion so the voltage becomes smooth. Dynamic capacitor switching operates through specific time intervals that ensures maximum voltage stability alongside THD reduction. A high-quality DC supply emerges from the filtered smoothed DC output for use in various applications.

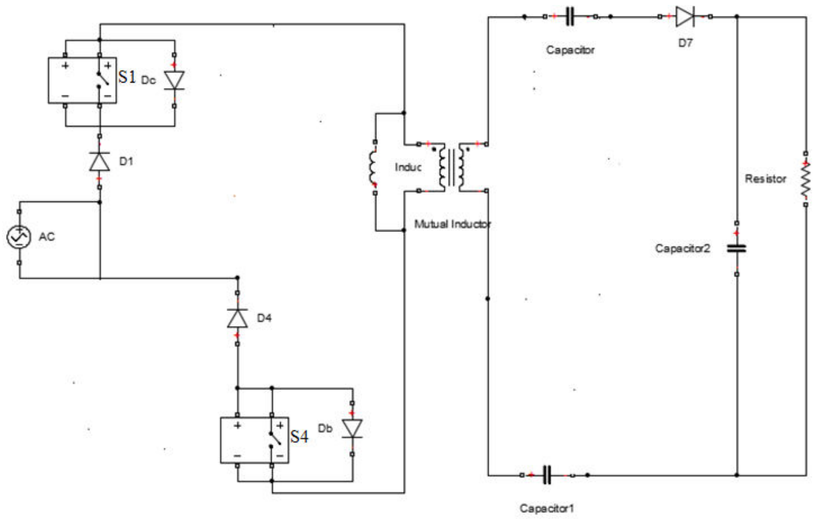

Figure 6: Circuit operation in mode-I

Mode 1: Figure 6 illustrates the circuit operation in **Mode-I** of the AC-DC converter using the Switching Capacitor Technique. In this mode, the system begins with the AC input from the three-phase grid, which is fed into the rectifier circuit. The rectifier converts the AC voltage into a pulsating DC waveform. In Mode-I, the switching capacitors are activated at specific intervals to manage the harmonic content of the output. The capacitors are switched in a manner that reduces the voltage ripple and harmonics by dynamically adjusting the phase and timing of the conversion process. This phase ensures that the DC output is smoothed, with the switching capacitors working to stabilize the voltage and lower the Total Harmonic Distortion (THD), improving the overall power quality.

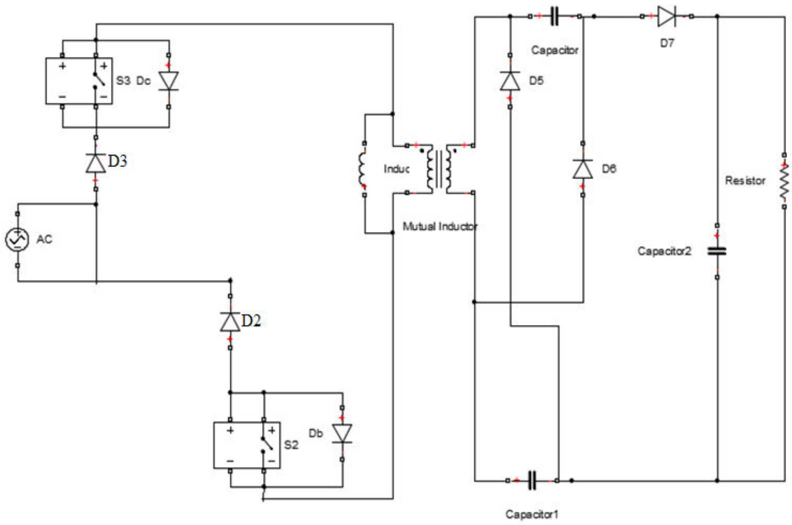

Figure 7: Circuit operation in mode-II

Mode II: Figure 7 depicts the circuit operation in **Mode-II** of the AC-DC converter using the Switching Capacitor Technique. In this mode, the circuit continues the conversion process after the initial rectification and capacitor switching in Mode-I. The focus in Mode-II is on fine-tuning the output by further reducing harmonic distortion and voltage ripple. The switching capacitors operate in a controlled manner to further smooth out the pulsating DC signal. The capacitors adjust their timing, ensuring that the converter's output is increasingly stabilized. In this phase, the system effectively cancels out remaining harmonics and minimizes Total Harmonic Distortion (THD), producing a cleaner and more efficient DC voltage output, which is then passed through a filter to ensure a high-quality, steady DC supply for downstream applications.

5. SIMULATION RESULT

The output waveform of the AC/DC Three-Level PWM Converter typically shows a DC signal with reduced ripple and harmonic distortion compared to traditional rectification methods. This waveform consists of distinct stepped levels, created by the three-level Pulse Width Modulation (PWM) control technique. The AC input, typically a sinusoidal waveform, is rectified and converted into a pulsating DC output. However, the three-level PWM technique uses controlled switching to modulate the voltage levels, reducing the peak-to-peak ripple. The resulting DC output waveform is much smoother, with fewer fluctuations and lower Total Harmonic Distortion (THD). The stepped nature of the waveform represents the three distinct voltage levels that the converter can switch between, ensuring a stable, high-quality DC supply for sensitive loads and improving system efficiency.

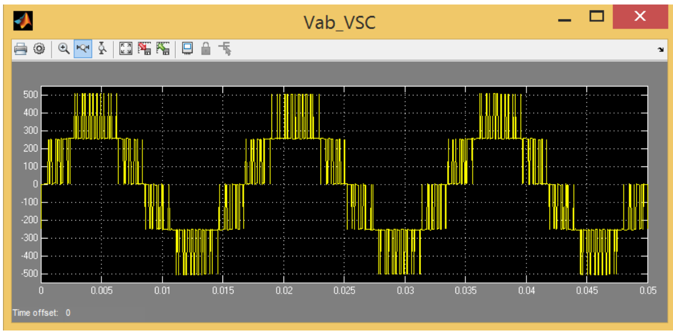

Figure 8: Output waveform of the AC/DC Three Level PWM Converter

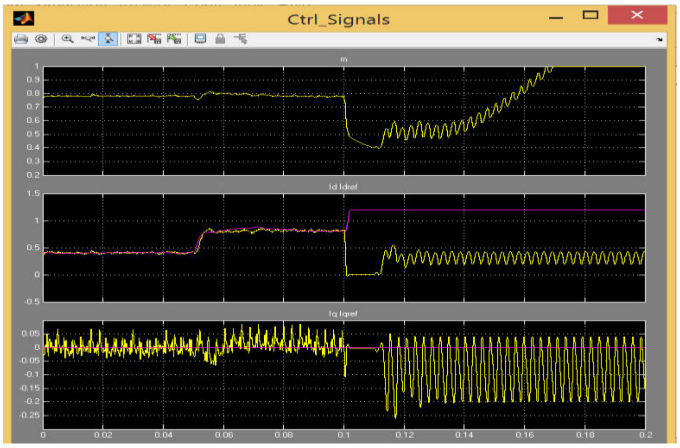

Figure 9: Output waveform of the AC/DC Three Level Control Signal PWM Converter

Figure 9 displays the output waveform of the AC/DC Three-Level Control Signal PWM Converter. In this figure, the AC input is converted into a DC output using a three-level Pulse Width Modulation (PWM) technique. The waveform illustrates the smoother, more controlled DC output compared to a standard rectified waveform. The use of a three-level PWM technique helps reduce the ripple and harmonic distortion by ensuring that the switching devices operate at precise intervals, creating a more stable output. The waveform shows a stepped DC signal with minimal voltage fluctuations, demonstrating the effectiveness of the PWM control in maintaining a consistent and high-quality DC voltage. This method ensures lower Total Harmonic Distortion (THD), providing improved power quality for sensitive electronic loads and reducing overall system losses.

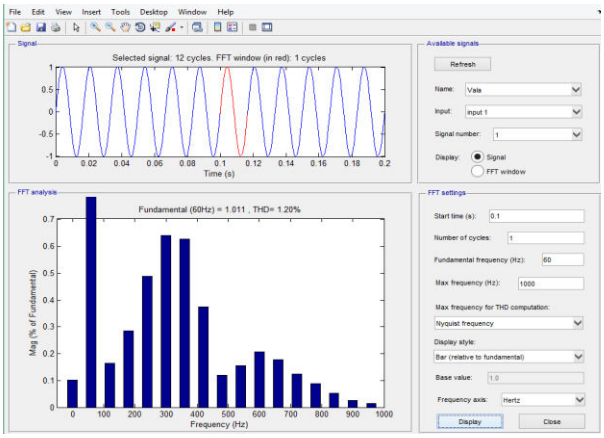

Figure 10: Total Harmonic Distortion

Total Harmonic Distortion (THD) is a measure of the distortion or deviation from a pure sinusoidal waveform, typically used to assess the quality of electrical signals like voltage or current. It quantifies the sum of harmonic components (multiples of the fundamental frequency) relative to the fundamental frequency itself. THD is expressed as a percentage, with a lower percentage indicating less distortion and better signal quality. High THD can lead to inefficiencies in electrical systems, such as increased heating in equipment, reduced lifespan of devices, and interference in communication systems. In power converters, minimizing THD is essential to ensure a cleaner, more stable output and to improve the overall performance and reliability of the system, especially for sensitive electronics.

6. CONCLUSION

This study presents an effective approach to minimizing Total Harmonic Distortion (THD) in a three-phase AC-DC converter using the Switching Capacitor Technique (SCT)**.** Through systematic design and simulation, the proposed method demonstrates significant THD reduction, improved power factor**,** and enhanced voltage regulation compared to conventional rectification techniques. The results indicate that SCT effectively shapes the input current waveform, reducing harmonic content without the need for bulky passive filters or complex active compensation circuits.

Furthermore, simulation results in MATLAB/Simulink validate the superiority of the proposed approach over traditional PWM-controlled rectifiers and passive filtering methods. The technique not only ensures compliance with IEEE 519 harmonic standards but also improves overall system efficiency, making it a viable solution for industrial and renewable energy applications. Future work may involve hardware implementation and real-time validation to further confirm the practical feasibility of the proposed method.

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