Triac Based Novel Single Phase Step-Down Cycloconverter with Reduced THDs for Variable Speed Applications

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Abstract: In variable speed applications, the cycloconverter-based AC to AC power conversion technique has gained more attention among researchers and academics than the traditional rectifier-inverter-based AC to AC power conversion process. The conventional rectifier-inverter-based AC to AC power conversion process has several disadvantages. It uses multi-power stages that increase the converter power conversion losses and increase the cost, volume, and weight of power losses. Besides high conduction and switching losses, the electromagnetic interference problems also accompany the above issues. In this regard, this paper proposes a novel step-down Triac based cycloconverter for variable speed control applications. The proposed topology uses only five Triac devices for one-third and one-fourth frequency conversion of 50 Hz with reduced total harmonics distortion without using any pulse width modulation techniques. The proposed model is designed in the MATLAB/SIMULINK environment. The simulation results show that around 18.85% and 23.67% of total harmonics distortions are reduced in the proposed converter for one-third and one-fourth frequency conversion of 50 Hz, respectively. Two physical experiments are carried out to prove the validity of the simulation results.

Keywords: cycloconverter; AC to AC power conversion; variable speed; switching loss; conduction loss; pulse width modulation

1. Introduction

The AC–AC solid-state converter converts an AC waveform into another AC waveform that allows arbitrary setting of output voltage and frequency [1]. Generally, there are two methods for this conversion. One method uses a rectifier and inverter-based converter, and another uses a cycloconverter. In a rectifier inverter-based converter, firstly, a rectifier circuit converts to DC voltage from AC voltage, and, finally, the inverter generates variable frequency from the rectifier output. This operation is also known as variable frequency drives (VFD) [2]; however, this VFD technique faces some difficulties. It consists of two conversion processes, and therefore requires large switching devices, which increases the cost and size of a system and decreases the efficiency of a system. Besides that, its output voltage contains higher total harmonics distortions (THDs) [3]. Therefore, a large size of the filter is needed to reduce this harmonics content, increasing the system cost and size. Furthermore, it uses a bulky multi-pulse phase-shifting transformer that leads harmonics in the grid. Consequently, the input power factor of a line decreases, which also curtails the power quality [4].

On the other hand, a cycloconverter provides direct AC to AC power conversion without any dc-link voltage. For this result, it utilizes fewer switching devices than the VFD technique. Therefore, it reduces the system cost and the size of the system. In 1930,
the authority of railway transportation in Germany first converted electricity from 50 Hz to 16–2/3 Hz in railways with arc rectifiers [5]. In 1950, a new cycloconverter was built with a varying speed and constant frequency for aircraft purposes using thyristors [6]. Following 1970, they were theoretically and practically analyzed [7]. Cycloconverters are normally phase controlled and traditionally use SCR because they are easy to switch phases with. The cycloconverter was developed in 1980 by replacing the thyristors with the soft switches [8]. Nowadays, it has gained the concern of the researchers as well as academics for performing as a variable speed controller in the rolling steel mill, cement industry applications, ship propellers, and SAG mill because of its low cost and complexity [9].

Biswas [10], Agarwal [11], Agarwal [12], Idris [13] and Khedekar [14] presented several new design topologies and applications for cycloconverters. They also launched different techniques related to static frequency changes. The improvement in design of cycloconverters was described following research and development in microcomputers due to their fast operating time, high speed performance, and reduced total power requirement. Figure 1 shows some conventional single-phase step-down cycloconverters for the conversion of the frequency to one-third and one-fourth its value [9–12]. Figure 2 displays the output of conventional cycloconverters which have higher total harmonics distortion. However, these cycloconverters were concluded from previous studies to have the following limitations:

- They cannot perform multi-frequency power conversion;
- The output voltage grieves from total harmonics distortions (THDs) problems;
- They still use large semiconductor devices, although they use fewer switching components than the VFD technique.

![Figure 1](image-url)

**Figure 1.** Conventional cycloconverters (a) Biswas [10], (b) Agarwal [11] (c) Agarwal [12] (1/3) and (1/4) frequency conversion of 50 Hz.
To reduce harmonics, several modulation techniques and conventional filters are used [15,16]. Nevertheless, it is not possible to reduce the harmonics contents by using conventional filters [17]. The tuned filter can be the solution to these problems. However, it makes the controlling complex. Therefore, a suitable modulation technique can be the best choice for reducing THDs. The various high frequency modulation techniques such as sinusoidal, space vector, trapezoidal, and delta modulation techniques are used to reduce THDs and improve the power quality [18–21]. However, these previously mentioned modulation techniques are not a proper solution for the problem. Since researchers are still working on it, this is the appropriate time to design a suitable topology aiming to reduce the overall cost, size, and total harmonic distortions. Therefore, these modulation techniques enhance design complexity and semiconductor costs that affect industrial applications at both lower and middle levels. As a result, the output of the conventional cycloconverter includes a large amount of harmonic distortion when used in these existing methods. Later on, microprocessor-based circuit and Field Programmable Gate Array (FPGA) technology had been introduced as a pulse generator circuit for higher frequency to lower frequency conversion. This cycloconverter’s output voltage contains the same amplitude sine pulse. The output voltage THD is therefore very high. However, the circuit based on the microcontroller is easy to implement and has a low cost [22,23].

In particular, third harmonic distortion affects nearly every machine operating parameter: supply voltage, torque output, torque ripple, motor temperature, vibrations, load stress, etc. Through analyzing the third harmonic distortion, the performance of the cycloconverter is crucial before an induction machine is connected to it. Several cycloconverter investigations have shown different operating factors. In [24], the researchers examine the extent to which harmonic output voltage spectrum improvements have been made, but suggest a complex circuit scheduling and modulation strategy to switch signal generation. As a result, for variable speed applications, cycloconverters with lower harmonics levels at their output are becoming more appealing than traditional cycloconverters [25]. However,
these cycloconverters are expensive and require skilled personnel for maintenance, and, therefore, they may not be cost-effective in all cases.

To solve the above problems, this paper introduces a novel single-phase step-down Triac based cycloconverter. The proposed topology uses five Triac devices for (1/3) and (1/4) frequency conversion of 50 Hz with reduced THDs by using a low frequency modulation technique. The main contributions of this paper are as follows:

- A novel Triac based step down AC to AC converter has been proposed;
- Reduction in the conventional inverter-based AC to AC converter problems;
- Reduction in total harmonic distortion, size, and weight of the cycloconverter.

2. Proposed Cycloconverter

Though a triac based cycloconverter topology had been proposed in ref. [26] for one third and one fourth frequency conversion which indication was only total Harmonics distortion. But in this paper, a cycloconverter topology has been introduced with a proper explanation of different modes which performance indicators are total device rating per power, total blocking voltage/voltage, the total number of switches, and total harmonics distortions. However, in this section, operating principle, harmonic analysis, and pulse generation procedure of introduced cycloconverter is briefly presented. The circuit diagram of the proposed cycloconverter is shown in Figure 3a. The proposed circuit has five Triac devices for single phase to single phase step down (1/3) and (1/4) frequency conversion of 50 Hz. The calculation of voltage stress plays an important role for cost as well as size of the cycloconverter. From Figure 3a, it is visible that the voltage stress of $T_1$ and $T_5$ will be subjected to the peak value ($V_m$) of supply voltage, $V_{in}$. On the other hand, the voltage stress of $T_2$, $T_3$, and $T_4$ switching devices will be ($V_m/2$). The individual voltage stress of individual switches is presented in Figure 3b.

![Figure 3. (a) Proposed cycloconverter topology (1/3) and (1/4) frequency conversion of 50 Hz; (b) voltage stress of individual switches of proposed cycloconverter.](image)

2.1. Operation

Here, the operating principle of the proposed single phase to single phase step down cycloconverter has been discussed. For reducing harmonics, the output of the proposed cycloconverter for one-fourth frequency conversion has been selected, as seen in Figure 4a. From this figure, it is observed that the total output consists of eight modes. The positive cycle of the proposed topology has consisted of the first four modes and the remaining modes are responsible for generating a negative half cycle. In that case, the input 50 Hz frequency is converted into $8 \times 50$ or 400 Hz. In the case of generating mode-1 of the output voltage, the firing pulse is given to the Triac $T_1$ and $T_4$. For this, the output voltage will be $V_m/2$. In mode 2, the firing pulse is given to $T_2$ and $T_3$ Triacs, then the output voltage will be $V_m$. In mode 3, the output voltage is $V_m$, this voltage can be generated by applying the pulse to the Triac devices $T_1$ and $T_5$. For generating mode 4, the current is flowing in Triac devices $T_3$ and $T_4$, the generated voltage of this mode is $V_m/2$. These modes 1, 2, 3, and 4 are for the positive level of output voltage.
where,

\[ V_{in} \]

and its voltage level is \(-\frac{V_m}{2}\). The final mode is mode 8, where the switching devices \(T_1\) and \(T_4\) are active and generating the voltage level of \(-\frac{V_m}{2}\). The modes of operation diagrams are presented in Figure 5 such that the red line indicates the current paths. Again, the same circuit can be used as one third frequency conversion of input frequency of 50 Hz. In this conversion, only six modes are used, which are presented in Figure 4b. The switching pattern for the one third and one fourth conversion is presented in Table 1.

![Figure 4](image-url)

\textbf{Figure 4.} Expected output response for (a) one-fourth frequency conversion and (b) one-third frequency conversion of proposed cycloconverter.

In mode 5, two switching devices, \(T_3\) and \(T_4\), are used for generating the required voltage level \(-\frac{V_m}{2}\). In mode 6, the current passes through the switching devices \(T_1\) and \(T_5\) and its voltage level is \(-\frac{V_m}{2}\). For generating the voltage of mode 7, the firing pulses are given to \(T_2\) and \(T_3\). The final mode is mode 8, where the switching devices \(T_1\) and \(T_4\) are active and generating the voltage level of \(-\frac{V_m}{2}\). The modes of operation diagrams are presented in Figure 5 such that the red line indicates the current paths. Again, the same circuit can be used as one third frequency conversion of input frequency of 50 Hz. In this conversion, only six modes are used, which are presented in Figure 4b. The switching pattern for the one third and one fourth conversion is presented in Table 1.

![Figure 5](image-url)

\textbf{Figure 5.} Cont.
Figure 5. Cycloconverter detailed operation of the eight modes for (1/3) and (1/4) frequency conversion of input frequency.

Table 1. Switching states of (1/3) and (1/4) frequency conversion of Input Frequency of the proposed model.

| Different Modes | T₁ | T₂ | T₃ | T₄ | T₅ | Output       |
|-----------------|----|----|----|----|----|--------------|
| Mode 1          | 1  | 0  | 0  | 1  | 0  | Vₘ/2         |
| Mode 2          | 0  | 1  | 1  | 0  | 0  | Vₘ           |
| Mode 3          | 1  | 0  | 0  | 0  | 0  | 0            |
| Mode 4          | 0  | 1  | 0  | 1  | 1  | Vₘ/2         |
| Mode 5          | 0  | 0  | 1  | 1  | 0  | −Vₘ/2        |
| Mode 6          | 1  | 1  | 0  | 0  | 0  | −Vₘ          |
| Mode 7          | 1  | 0  | 0  | 0  | 1  | −Vₘ/2        |
| Mode 8          | 1  | 0  | 1  | 0  | 0  | −Vₘ/2        |

2.2. Harmonic Analysis of Proposed Cycloconverter

In this subsection, the details of the harmonics spectrum of the proposed topology have been illustrated. The output voltage of a conventional cycloconverter can be written in terms of Fourier series as below:

\[ V₀(\omega t) = a₀ + \sum_{n=1}^{\infty} aₙ \cos\left(\frac{n\omega t}{m}\right) + bₙ \sin\left(\frac{n\omega t}{m}\right) \]  

(1)

where, \( m \) is the conversion ratio and \( n \) is the harmonic order.

Here,

\[ a₀ = \frac{1}{\pi l} \int_{0}^{\pi} V₀d(\omega t) \]

\[ = \frac{1}{\pi l} \left[ \int_{0}^{\pi} (Vₘ) \sin wt \, dt + \int_{2\pi}^{3\pi} (Vₘ) \sin wt \, dt + \int_{3\pi}^{4\pi} (-Vₘ) \sin wt \, dt + \int_{4\pi}^{5\pi} (-Vₘ) \sin wt \, dt + \int_{5\pi}^{6\pi} (-Vₘ) \sin wt \, dt \right] = 0 \]  

(2)
The fundamental component of the conventional cycloconverter can be written as:

\[ a_n = \frac{1}{3\pi} \int_0^{6\pi} V_0\cos\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ = \frac{1}{3\pi} \left[ \int_0^{\pi} (V_m)\sin\omega t \cos\left(\frac{nw_1}{m}\right)d(\omega t) \right. \]
\[ + \int_\pi^{2\pi} (V_m)\sin\omega t \cos\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_2\pi^{3\pi} (V_m)\sin\omega t \cos\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_3\pi^{4\pi} (V_m)\sin\omega t \cos\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_4\pi^{5\pi} (V_m)\sin\omega t \cos\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_5\pi^{6\pi} (V_m)\sin\omega t \cos\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ = 0 \]  

and,

\[ b_n = \frac{1}{3\pi} \left[ \int_0^\pi (V_m)\sin\omega t \sin\left(\frac{nw_1}{m}\right)d(\omega t) \right. \]
\[ + \int_\pi^{2\pi} (V_m)\sin\omega t \sin\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_2\pi^{3\pi} (V_m)\sin\omega t \sin\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_3\pi^{4\pi} (V_m)\sin\omega t \sin\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_4\pi^{5\pi} (V_m)\sin\omega t \sin\left(\frac{nw_1}{m}\right)d(\omega t) \]
\[ + \int_5\pi^{6\pi} (V_m)\sin\omega t \sin\left(\frac{nw_1}{m}\right)d(\omega t) \]

after simplification,

\[ V_0(\omega t) = \frac{V_m}{3} \sin(\omega t) + \sum_{n=1,5,7,\ldots}^{\infty} \frac{24V_m\sin\left(\frac{n\pi}{3}\right)}{\pi(m^2-n^2)} \sin\left(\frac{n\omega t}{m}\right) \]  

(5)

The first term of Equation (5) represents the third harmonics component, and the remaining term represents the other harmonics component without third harmonics value. The fundamental component of the conventional cycloconverter can be written as:

\[ V_{01}(\omega t) = \frac{24V_m\sin\left(\frac{\pi}{3}\right)}{\pi(m^2-1)} \sin\left(\frac{\omega t}{3}\right) \]  

(6)

In the case of the proposed one-third cycloconverter, the output has six half cycles, but their values are same as a conventional cycloconverter. The output voltage of the second and fifth half cycle is \(V_n\) and the output of the remaining half cycles is \(\frac{V_n}{2}\). Therefore, the output of the proposed cycloconverter can be written as below in terms of Fourier series expansion.

\[ V_0(\omega t) = \sum_{n=1,5,7,\ldots}^{\infty} \frac{18V_m\sin\left(\frac{n\pi}{3}\right)}{\pi(m^2-n^2)} \sin\left(\frac{n\omega t}{3}\right) \]  

(7)

The fundamental frequency of output voltage can be obtained by using \(n = 1\).

\[ V_{01}(\omega t) = \frac{18V_m\sin\left(\frac{\pi}{3}\right)}{\pi(m^2-1)} \sin\left(\frac{\omega t}{3}\right) \]  

(8)

From Equation (7), it is clear that the proposed cycloconverter fully eliminates third harmonics components, which later reduces the total harmonic distortions.

2.3. Pulse Generation Procedure

In this subsection, the details of the pulse generation procedure in the proposed cycloconverter are illustrated. For the pulse generation, the low frequency modulation technique named as firing angle calculation method is used. Because the high frequency
modulation techniques not only increase the total harmonics distortion but also increase the switching losses and voltage stress of switching devices, which also reduces the system efficiency. The switching pulses for one third and one fourth conversion of input frequency 50 Hz are displayed in Figures 6 and 7 respectively.

**Figure 6.** Firing pulses of different Triac of proposed cycloconverter for one-third conversion of 50 Hz.

**Figure 7.** Firing pulses of different Triac of proposed cycloconverter for one-fourth conversion of 50 Hz.

### 3. Simulation and Experimental Results

This section deals with the simulation results of the proposed cycloconverter. Here, low frequency pulses are used for turning on the switching devices. The total simulation is done in the MATLAB/SIMULINK environment. Basically, the cycloconverter is used for controlling the speed of asynchronous motors such as a single phase induction motor which is simulated as an inductive load. The simulation parameters for the inductive load are illustrated in Table 2. Figures 8 and 9 display the output voltage and current of

| Parameters      | Values         |
|-----------------|----------------|
| Nominal Power   | 187 VA         |
| Voltage (rms)   | 220 V          |
| Frequency       | 50 Hz          |
| Main winding R  | 2.02 ohm       |
| Main winding L  | 7.4 mH         |
| Main winding R  | 4.12 ohm       |
| Main winding L  | 5.6 mH         |
| Mutual Inductance | 177 mH      |
| Auxiliary winding R | 7.14 ohm  |
| Auxiliary Inductance | 8.5 mH   |
| Capacitor Start R | 2 ohm       |
| Capacitor Cs    | 254.7 𝜇F       |

Figures 10–14 display the harmonic spectrums of voltage and current.
the proposed cycloconverter for its one third frequency conversion of input frequency for motor load, respectively. From this figure, it is realized that the output voltage and current of the proposed topology face some distortions. The harmonic spectrums of voltage and current have been displayed in Figure 10. Again, the output voltage of the proposed topology for its one fourth frequency conversion of 50 Hz in terms of resistive load is shown in Figures 11–14, which show the voltage, current, and frequency spectrum of proposed topology, respectively. Here, also, the output voltage and current face the harmonic distortion when the loads are motors.

**Table 2. Simulation Parameters of inductive Load.**

| Parameters                  | Values                        |
|-----------------------------|-------------------------------|
| Nominal Power               | 187 VA                        |
| Voltage (rms)               | 220 V                         |
| Frequency                   | 50 Hz                         |
| Main winding Stator         | $R_s = 2.02 \text{ ohm, } L_s = 7.4 \text{ mH}$ |
| Main winding Rotor          | $R_r = 4.12 \text{ ohm, } L_s = 5.6 \text{ mH}$ |
| Mutual Inductance           | 177 mH                        |
| Auxiliary winding stator    | $R_{as} = 7.14 \text{ ohm, } L_{as} = 8.5 \text{ mH}$ |
| Capacitor Start             | $R_{st} = 2 \text{ ohm, } C_s = 254.7 \mu F$ |

**Figure 8.** Output voltage of one-third frequency conversion of input frequency for motor load.

**Figure 9.** Output current of one-third frequency conversion of input frequency for motor load.
Figure 8. Output voltage of one-third frequency conversion of input frequency for motor load.

Figure 9. Output current of one-third frequency conversion of input frequency for motor load.

Figure 10. Harmonics spectrum of one-third frequency conversion of input frequency for motor load: (a) voltage; (b) current.

Figure 11. Output voltage of one-fourth frequency conversion of input frequency for resistive load.

Figure 12. Output voltage of one-fourth frequency conversion of input frequency for motor load.

Figure 13. Output current of one-fourth frequency conversion of input frequency for motor load.
To verify the simulation results, two physical experiments took place for the proposed cycloconverter; the first one is achieving one-third conversion of 50 Hz while the second experiment is achieving one-fourth conversion of 50 Hz. The two experiments controlled the voltage of a resistive load. The equipment used in the two experiments are mentioned in Table 3 and the setup of the two experiments is shown in Figure 15:

Table 3. Prototype Components.

| Title                          | Specifications                      |
|-------------------------------|-------------------------------------|
| Input voltage (AC)            | 220 V, 50 Hz                        |
| Center trapped Transformer    | 12-0-12, 3 amp                      |
| Triacs                        | BT136                               |
| Optoisolator                  | MOC30216                             |
| Zero crossing detector        | Half wave rectifier with 4n35 IC    |
| Microcontroller Board         | Arduino Uno (atmega328p)            |

Figure 14. Harmonics spectrum for voltage and current of one-fourth frequency conversion of input frequency for motor load. (a) voltage; (b) current.
To verify the simulation results, two physical experiments took place for the proposed cycloconverter; the first one is achieving one-third conversion of 50 Hz while the second experiment is achieving one-fourth conversion of 50 Hz. The two experiments controlled the voltage of a resistive load. The equipment used in the two experiments are mentioned in Table 3 and the setup of the two experiments is shown in Figure 15:

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| Zero crossing detector       | Half wave rectifier  |
| with 4n35 IC                 |                      |
| Microcontroller Board        | Arduino Uno (atmega328p) |

Figure 15. Physical experiment setup of the proposed cycloconverter controlling the voltage of resistive load.

The results in Figure 16 show that the output voltage displayed by the Oscilloscope is the same as that of the expected results shown in Figure 4 and the simulation result in Figure 11.

Figure 16. Physical experiments output responses of proposed cycloconverter for one-fourth frequency conversion on the left and one-third frequency conversion on the right.

4. Mathematical Verification of Total Blocking Voltage

The blocking voltage is the voltage that appears across a switch when it is reverse biased, and the total blocking voltage is the summation of the individual blocking voltages of the requirement of each switch of a topology. The TBV of the conventional cycloconverter shown in Figure 1a can be calculated as shown in Equation (9).

\[ TBV = V_{T1} + V_{T2} + V_{T3} + V_{T4} \]  (9)

The blocking voltage of \( T_1, T_2, T_3, \) and \( T_4 \) switching device is \( V \).

Therefore, the total blocking voltage is:

\[ TBV = V + V + V + V = 4V \]  (10)

Therefore, the total blocking voltage/voltage = 4 for the conventional cycloconverters. The proposed cycloconverter in Figure 3a has the blocking voltage for Triac devices \( T_1, T_2, T_3, T_4, \) and \( T_5 \) as \( V, (V/2), (V/2), (V/2), \) and \( V \), respectively. The TBV/V for the proposed cycloconverter equals 3.5 less than that of the conventional one.
5. Comparative Analysis

This section deals with the detail comparison among different topologies based on various performance indicators such as total number of switches, total blocking voltage per voltage (TBV/V), total device rating per power (TDR/P), and total harmonics distortions (THDs). The first important comparable parameter is number of switches. This parameter has a direct relationship with the cost and size of a converter topology. For this reason, to design a converter topology, it must be ensured that the proposed cycloconverter topology uses the lowest amount of switches.

From Figure 17a, it is clear that the proposed topology uses the second-lowest number of switching devices. On the other hand, Biswas [10] and Idris [13] topologies use the lowest number of switches, and Idris [13] also uses 4 diodes. The lowest number of switches has been observed for Agarwal [11], Agarwal [12], and Khedekar [14] topologies.

![Figure 17](image.png)

**Figure 17.** Comparative analysis among different cycloconverter topologies based on (a) no. of switches, (b) TBV/V, (c) TDR/P, and (d) THDs.
The other significant indicator is total blocking voltage/voltage (TBV/V), which also has a direct impact on the cost of a converter topology. To minimize the cost of the converter topology, the TBV/V has to be kept as small as possible. A comparison among different cycloconverter topologies based on TBV/V is presented in Figure 17b. This figure indicates that the proposed topology has the lowest TBV/V, whereas the highest number is observed for Agarwal [11], Agarwal [12], and Khedekar [14]. Therefore, the proposed topology will offer a low cost for designing.

Another parameter is total device rating per power (TDR/P), which is calculated by the following equation:

\[ TDR = \sum_{i=1}^{sw} (V_{si} \ast I_{si}) \]  

where \( V_{si} \) and \( I_{si} \) are the voltage and current of a switching device, respectively. TDR also has a direct impact on the size and cost of a converter. The large value of TDR/P means a high cost and size of the converter topology. Therefore, as TDR/P becomes smaller, the topology is more cost effective. Figure 17c presents the comparative analysis among different types of cycloconverter topologies based on total device rating per power (TDR/P), and also illustrates that the proposed topology achieves less than the other mentioned topologies. Therefore, in the case of TDR/P, the proposed topology offers the optimal performance.

The last comparable indicator is the total harmonics distortions (THDs), which reduces the lifetime of switching devices. Besides, the high value of THDs creates heating losses and can cause false triggering. Therefore, for the design of cycloconverter, achieving a low value of THDs is essential in this era. Figure 17d displays comparative results among different cycloconverter topologies based on THDs. It is observed from Figure 17d that the proposed topology has the lowest amount of total harmonics distortions than other topologies, which indicates that the proposed topology drives the systems to the finest performance in the case of THDs.

6. Discussion

- The cycloconverter is a candidate substitution for the VFD in the future, due to its smaller size and components. Many research works are focusing on the design of the cycloconverter, considering the aim of achieving less size and components with less total harmonic distortion at the same time.

- The proposed method in this research uses five Triac switches in the cycloconverter to create five modes in order to change the frequency to one third and one fourth the normal frequency (50 Hz). Four indicators (THD, TDR/P, TBV/V and no. of switching devices) are used to evaluate the proposed cycloconverter with other state of the art methods. The results show that the proposed method has the lowest THD and has better TBV/V than [10–14]. The proposed method has less components than [11–14] but more than [10] by one switch, which enables lower THD.

- Two physical experiments were carried out to prove the validation of the expected and simulated results of the proposed cycloconverter to convert frequency to one-third and one-fourth of its value. The physical experiments results behave the same as those of the simulated and expected ones.

- The proposed cycloconverter can be used in a wide variety of applications such as water pumping using renewable energies, cement factories, steel factories, and all of the heavy industries [27,28]. Many new applications are going to benefit from the proposed cycloconverter, such as floating photovoltaics applications in dams [29], where pumping control is very important in standalone applications, as well as offshore wind, tidal, and waves generation control in standalone and grid tied applications in terms of gates and pumps control [30]. The proposed cycloconverter can also be used in the controlling of solar thermal energy systems and biomass converters [31,32]. The cycloconverter can also be used in small and large scale hydro pumped energy storage systems, especially in buildings [33]. One other application is ultraviolet water disinfection systems, as the system includes a variable speed motor pump unit [34].
In future research, the authors will focus on the application of the proposed technique on the standalone wind energy generation for feeding factories.

7. Conclusions

This paper introduces a novel cycloconverter topology that will minimize the problems of the rectifier–inverter-based AC to AC power conversion process. Besides, in the conventional cycloconverter, a large amount of THDs is produced and the proposed topology reduces the THDs by more than 25% of the conventional topologies such as [11,12], and in case of [10], the reduced amount is less than 10%. In addition, the proposed cycloconverter uses less switching devices, total device rating/power, and total blocking voltage than other state of the art topologies. The physical experiments applied to the proposed cycloconverter proved the validity of the simulation results with identical behavior. The proposed cycloconverter is a candidate application for standalone renewable energy systems, especially wind turbines and heavy industries.

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