AC Mains Harmonics Compensation Approach by Passive Multipulse AC-DC Converter

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ABSTRACT : *In this research article, a passive 48-pulse rectifier is proposed to mitigate the AC input line current harmonics. Harmonics arises due to the inculsion of nonlinear loads in our power system. As, more or less all the power electronic apparatus inculding rectifiers are known as a highly reputed non linear device so, they can have a severe effect on the power system. The proposed rectifier scheme shows a THD of 4.88% having a partial inductive load. The resultant THD value of the AC supply current can fulfill the requirements of IEEE 519-1992 standard for harmonics control. The design is done by utilizing a 24-pulse diode rectifier and evolving it into a 48-pulse rectifier by cascading a UIT based pulse doubling circuit. The proposed rectifier can mitigate lower than 47th order harmonics. This paper also inculdes the operating principle of the desinged scheme with proper equations.*
KEYWORDS: *Unconventional Interphase Transformer (UIT), Pulse Multiplication Circuit, Multipulse Rectifier (MPR), Total Harmonic Dstortion (THD).*

I.   INITIATION

Power electronics is a combination of power, electronics and control. With the increasing demand of energy now-a-days, power converters gain a huge amount of value in modern era. Power converters are used as a common interphase between AC-DC or AC-AC conversion system. As the volt ampere ratings and switching frequency characteristics of modern power electronic devices are keep improving so, the range of application continues to expand in areas such as MW industrial drives, electrical power transmission, transportation and many such types of applications [1]. As the all the power electronic devices are nonlinear type so it can inject harmonics into the AC input line current [2]. This harmonics causes voltage distortion which can have a severe effect on power grids such as blowing circuit breakers, unwanted relay operation, generate voltage drops on distribution channels due to skin effect, causing crosstalk because of proximity effect generated by the current harmonics on communication channels, generating heat on household products associated with the power grid and many more [3]. So, to limit the voltage distortion we have to control the total harmonic distortion (THD) of the input current. To mitigate this harmonics problem referred to known standards is an alarming headache for modern power electronic researchers. IEEE 519-1992 standard recommendation is a highly reputed reference to mitigate the harmonics which suggests that the THD content of a system must be less than 5% of the fundamental frequency [4].

There are many ways to control the THD content of the AC line currents and power converter researchers have developed a lot of ideas till current date to mitigate this harmonics problem [5]. THD can be mitigated by using filters, using multipulse rectifiers or using current injection methods. But filters not only make a system bulky but also produces other unwanted problems such as generating series or parallel resonance, producing uncontrollable filter currents, having switching frequency limitation etc. [6-7]. On the other hand MPRs are also a simple way to compensate harmonics. But MPRs is a costly process because it employs a large number of electronic as well as static power devices [8]. An MPR may be divided into controlled or active type and uncontrolled or passive type. Passive rectifiers has an advantage on cost efficiency over active filters because it does not need any gate pulse generating circuit which is a crying need for proper operation of the active element employed by the controlled rectifiers [9]. A rectifier tree is depicted in Fig. 1 which shows all

possible multipulse rectifiers that can be used for harmonics control approach. Last one is the current injection method which is nothing but applying pulse multiplication circuit for THD mitigation. Pulse doubling, pulse tripling or even higher pulse multiplication circuits are available [10-12]. But sometimes pulse multiplication circuit is quite complex for both simulation and practical implementation [13]. So, utilizing lower MPRs and by adding a proper pulse multiplication circuit with that can be a cost effective and simple approach for limiting harmonics content of the AC mains.

Fig.1. Topology architecture of rectifier tree.

In 2011, F. Meng *et al.* [14] proposed a 12-pulse converter for active harmonic suppression. C. Young *et al.* [15] proposed and experimentally setup an 18-pulse diode rectifier in 2014. In 2018, S. Khan and his group of researcher proposed an 18-pulse diode rectifier using autotransformer [16]. All the schemes described above cannot meet IEEE 519-1992 standard requirement. In 2019, Y. Lian *et al.* [12] proposed a 48-pulse active rectifier using current injection method. That schemes prototype was also developed by the authors but being an active rectifier it increased the cost and complexity of the overall system. S. Akther and his teammates proposed a SIPR based pulse doubling associated 48-pulse passive converter which can meet the standard requirement [17]. But that was made for only resistive load and no further works or guideline provided to make that scheme for inductive loads. In this research work, we utilize conventional 24 pulse diode rectifier and by adding a passive pulse doubling circuit with it for making it into a 48-pulse passive rectifier. Our proposed model shows an input current THD of 4.88% having an R-L load that can meet the needs of IEEE 519-1992 standard.

II. RESEARCH WORKFLOW

Fig. 2 displays the workflow of the research work. At first 3-phase balanced AC supply is given into suitable transformer. Here we are dealing with only zigzag phase shifting transformers. Then to design the conventional 24-pulse diode rectifier. Here a question arises i.e. why 24-pulse? Why not 12-pulse or lower pulse rectifiers are taken into consideration. The main reason behind it that lower than 24-pulse rectifier are not able to meet the IEEE standard requirement. And the proposed pulse doubling circuit we have designed is only takes two input. So, either a 12-pulse or 24-pulse rectifiers should be used. As, 12 multiplies into 2 makes a 24-pulse rectifier is not enough to meet the desired conditions we are looking for so, 24-pulse diode rectifier is used. After than our unconventional interphase transformer (UIT) based passive pulse doubling circuit comes into action. Then to combine the pulse doubling circuit with the conventional rectifier for making it into a higher pulsed rectifier. After than the proposed design is simulated by using MATLAB Simulink which is a very effective tool for these kinds of simulations. After that the input current curve of the proposed design and THD

content is visualized by the Simulink model. At last justification of the model lies in comparison of the proposed design with other designs.
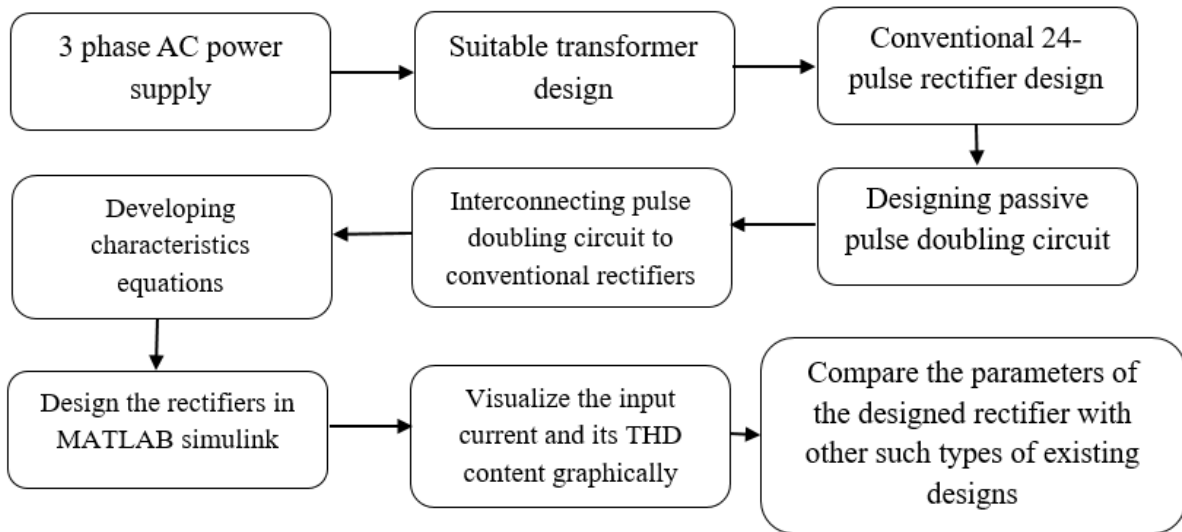

Fig. 2. Workflow of the research work.

III. PROPOSED MULTIPULSE CONVERTER

Fig. 3 shows the circuit configuration of the proposed multipulse converter. There are four phase shifting transformer. Each transformer is attached with three pair of power diodes forms a six pulse rectifier. Exact phase shifting achieved by adding extra windings with the fundamental transformer windings. Though it can reduce the transformer utilization factor but it has good output power quality and isolation facilities. Rectifier-2 and rectifier-3 is connected with interphase reactor-1 (IR-1) and makes a 12-pulse rectifier. Similarly rectifier-1 and rectifier-3 connected by IR-2 for making it another 12-pulse rectifier. This 12-pulse plus 12-pulse i.e. total 24-pulse rectifier is further pulse doubled by our UIT based pulse doubling circuit and gives an output of 48-pulse. UIT based pulse doubling circuit is totally passive in nature as it contains two additional power diodes i.e. D_P and D_Q. UIT based pulse doubling circuit has three operating modes which described below:
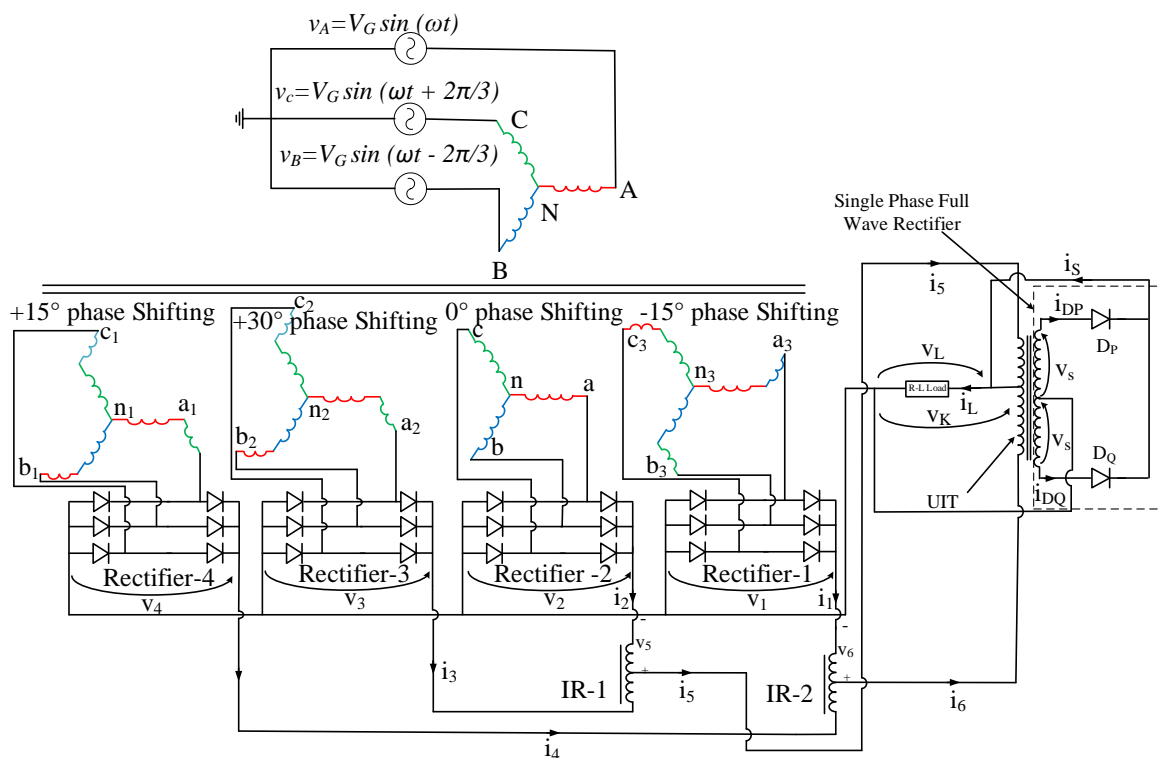

Fig. 3. Circuit configuration of the proposed 48-pulse rectifier.

General Mode: When secondary voltage (V_S) of the UIT is less than zero then both of the diodes are in reversed biased condition. In general mode, all the four rectifiers are active. So, load current becomes equal to the summation of IR-1 current (i_5) IR-2 current (i_6). The circuit configuration of load current is given in Fig. 4.
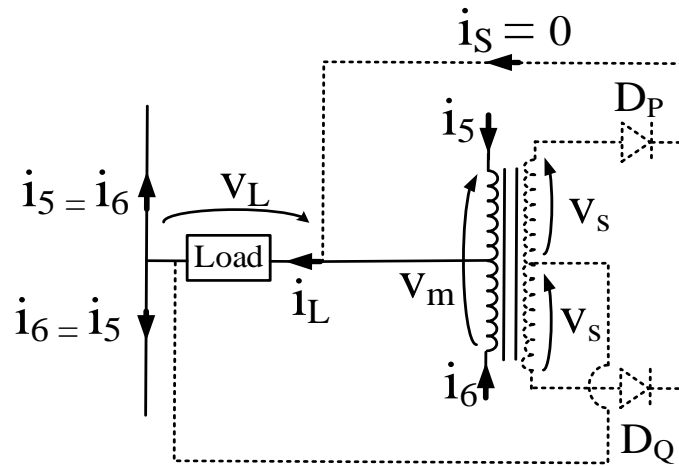
$$i_L = i_5 + i_6 \tag{1}$$

Fig. 4. Circuit configuration of general mode.

P-Mode: When secondary voltage (V_S) of the UIT is greater than the load voltage (V_L) then diode D_P is forward biased and diode D_Q is reversed biased which is depicted in Fig. 5. In this mode IR-1 is active and IR-2 is inactive. Diode current i_{DP} is injected to the load. Equation of the currents i_5 and i_{DP} is given in equation (2) and (3) respectively. Where, k is the turns ratio of the proposed UIT.

$$i_5 = \frac{k}{0.5+k} \tag{2}$$
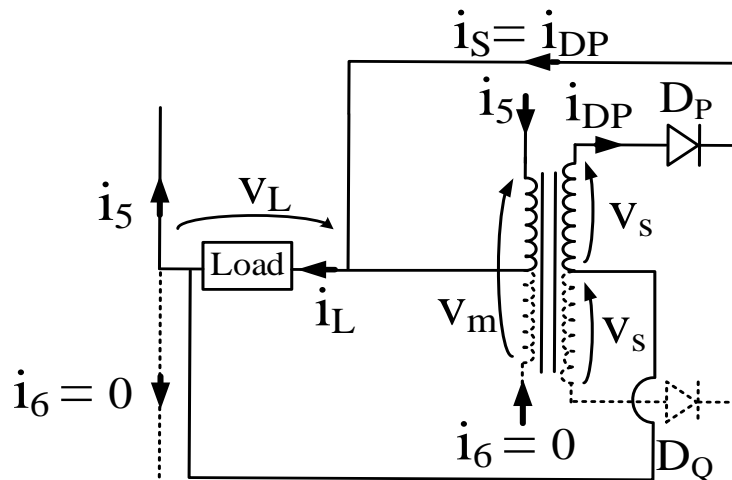
$$i_{DP} = \frac{0.5}{0.5+k} \tag{3}$$

Fig. 5. Circuit configuration of P-mode.

Q-Mode: When modulus of the negative secondary voltage (V_S) of the UIT is greater than the load voltage (V_L) then diode D_Q is forward biased and diode D_P is reversed biased which is depicted in Fig. 6. In this mode IR-2 is active and IR-1 is inactive. Diode current i_{DQ} is injected to the load. Equation of the currents i_6 and i_{DQ} is given in equation (4) and (5) respectively. Optimal turns ratio of the UIT is given in equation (6).

$$i_6 = \frac{k}{0.5+k} \tag{4}$$

$$i_{DQ} = \frac{0.5}{0.5+k} \tag{5}$$

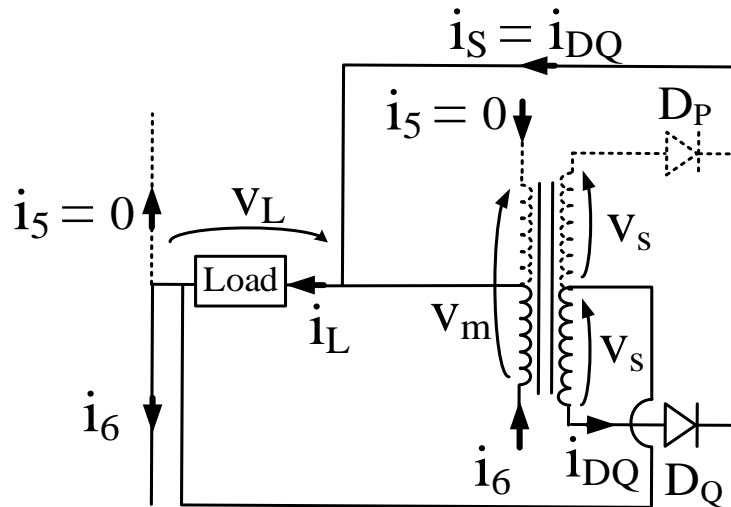*Optimal turns ratio,* $k = \frac{N_S}{N_P} = 58.9$ (6)

Fig. 6. Circuit configuration of Q-mode.

IV. SIMULATION AND FINDINGS

For the simulation MATLAB Simulink tool is used for designing the proposed 48-pulse rectifier scheme. There are some values undertaken as the specific values for the simulation which are given in Table 1.

Table 1: Simulation Specification

Parameters	Values
Line-line input voltage (rms)	400 V
Frequency of the input	50 Hz
Transformers turns ratio	1:1
Output (rated)	200 KW
Turns ratio of the UIT	1:58.9

After simulation the input current curve of proposed converter is depicted in Fig. 7. From Fig. 7 it is clear that the current contains a little bit of harmonics and its harmonics content is shown in Fig. 8 which is the FFT spectrum curve of that input current. From Fig. 8 it is clear that the THD content of the input current is 4.88% at full load. Output voltage curve is shown in Fig. 9 and a zoomed version of that output voltage is depicted is Fig 10 from which it is obvious that the difference between higher and lower peak of the output voltage is typically one volt. This ensures less voltage fluctuation and thus good output power quality.
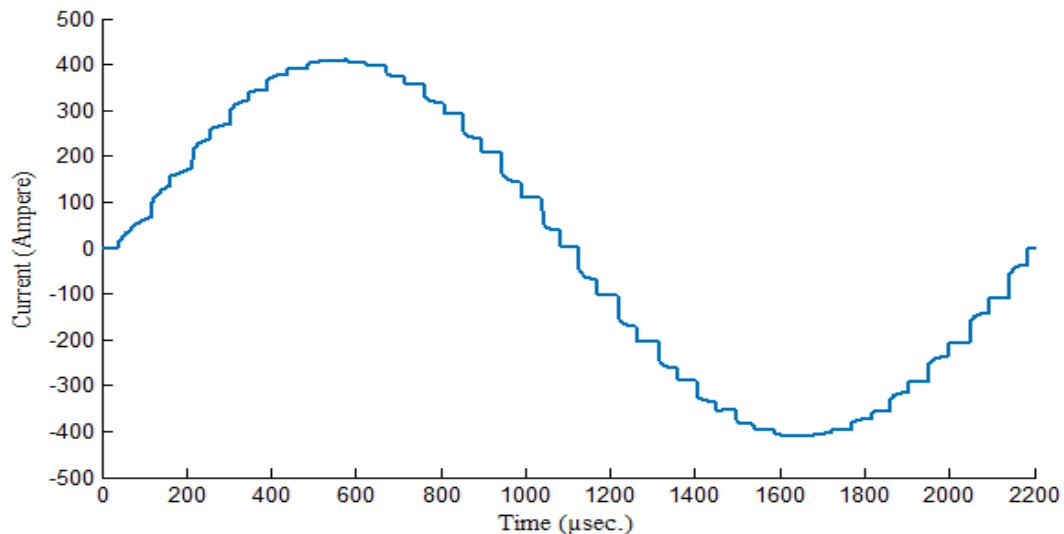

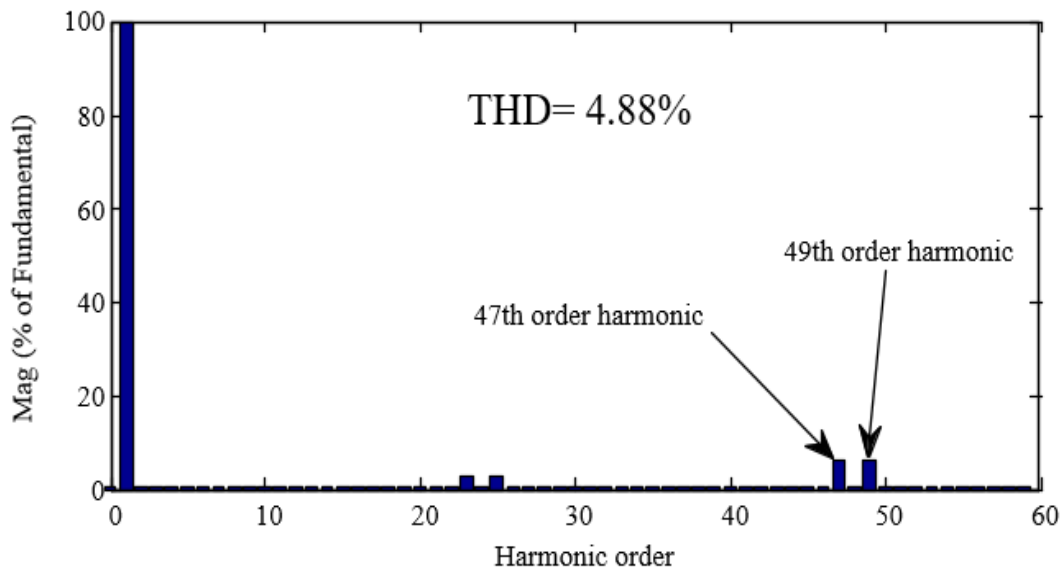**Fig. 7.** Input current waveform of the proposed 48-pulse rectifier.

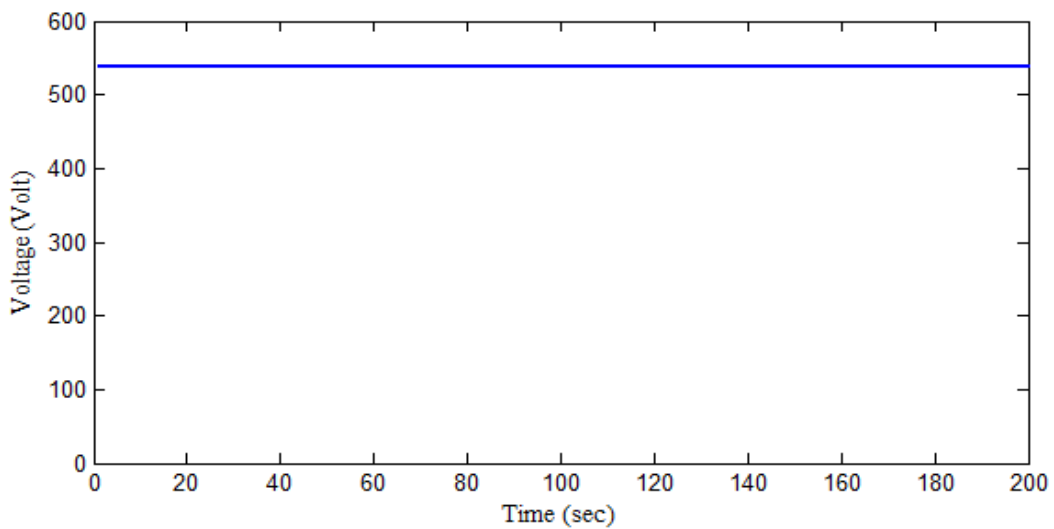**Fig. 8.** THD content of the input current.
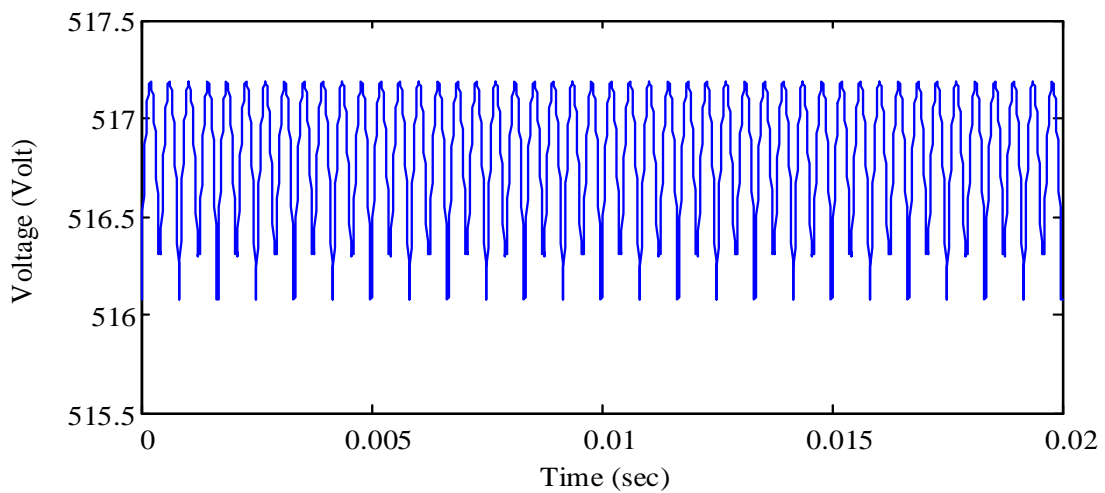

Fig. 9. Output voltage waveshape.

Fig. 10. Zoomed version of the output voltage.

V.   CESSATION AND FUTURE PERSPECTIVES

IEEE 519-1992 standard states that, the THD content of a system must be less than 5% of the fundamental frequency. So, our proposed rectifier can fulfill the requirement of that standard because it shows a THD of 4.88% which id of course less than 5%. Moreover, the simulation was made for R-L loads where most of such types of existing designs was made only for resistive loads. Where conventional 48-pulse rectifier needs eight costly phase shifting transformers along with 48 power diodes, our proposed scheme needed only four zigzag transformers along with two interphase reactors and a UIT. The number of electronic component i.e. power diodes used in the designed scheme are also lower in number (26 power diodes in total). This results in cost effective and simple approach for harmonic compensation. The future work related to this research lies in developing a laboratory prototype of the proposed scheme. The resulting THD of the practical model will must be less than the designed THD result because of line reactance. This model can be applied to various applications like variable frequency drives, ship traction system, electrochemical process or even HVDC generation.

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