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Design of a Passive 48-Pulse AC-DC Converter for THD Stabilization at Light Load

***Abstract**. In this paper a 48-pulse uncontrolled AC-DC converter is proposed to mitigate AC line current harmonics of the input side. The proposed rectifier uses conventional 24-pulse parallelly connected rectifier with addition of a passive current injection circuit named as special interphase reactor. The interphase reactor consists of two additional lower rated power diodes. The value of the found THD is 3.55% which satisfies the IEEE 519-1992 standard. Proposed converter also shows lower fluctuation of harmonics valued 1.40% with respect to full load ensuring stable operation at light load. Designed multipulse converter scheme is also simple in construction and requires less number of electronic devices compared to conventional 48-pulse AC-DC converter. This article also explains the simulation and THD performance of the proposed AC-DC converter with proper figures.*

Streszczenie.** W artykule przedstawiono 48-pulsowy przekształtnik AC-DC ze zmniejszoną wartością harmonicznych prądu na wejściu. Proponowany prostownik wykorzystuje 24-pulsowe konwencjonalne prostowniki połączone równolegle z dodatkiem obwodu prądowego nazwanego międzyfazowym reaktorem. Składa się on dwóch dodatkowych diod. Osiągnięto współczynnik THD mniejszy niż 3.55%. Proponowany układ charakteryzuje sie też mniejszą fluktuacja harmonicznych. **Projekt pasywnego 48-pulsowego przekształtnika AC-DC o małym współczynniku THD

Keywords: Total harmonic distortion (THD), Zigzag transformer, MATLAB simulink, Special interphase reactor (SIPR).
Słowa kluczowe: przekształtnik AC-DC, współczynnik THD

Introduction

AC-DC converters are basically known as rectifiers. With the increasing electricity demand of the present world harmonics is caused mainly due to the inclusion of non-linear loads in modern power systems. So, harmonics are generated by almost all types of converters resulting remarkable problems on AC mains, loads and distribution systems [1]-[3]. This harmonics problem becomes more severe at light load i.e. 20% of the full load [4]. Therefore the suppression of the harmonics to control the total harmonic distortion (THD) in allowable ranges referred to known standards is designated as a very important matter in modern power system [5].

For reducing the harmonics of the input AC line current, different types of filters such as active filters and passive filters have been proposed in different rectifier schemes [6]-[7]. But there are some problems occured while working with passive filter such as introduction of series or parallel resonance, unpredictable filter current, reactive power generation and bulkiness of the device alongside active filters have strict limitation on switching frequency of the electronic devices [8-9]. Voltage source converter (VSC) based multipulse rectifiers are also being used for harmonics mitigation and applicable to HVDC systems but these types of schemes also suffer with very high switching frequency of the electronic devices [10]. Increasing the pulse number of a rectifier by pulse doubling or pulse tripling techniques are also popular choices for mitigating harmonics [11-12]. Controlled as well as uncontrolled multipulse rectifier (MPR) schemes can also be used for reducing harmonics but controlled rectifier schemes come with many undesirable facts like reactive power generation, current ripple, need of power filters, extra circuitry requirement for generating gate pulse etc. [13-14]. So, it is flexible as well as a cost effective approach to use passive or uncontrolled rectifiers for harmonic compensation.

In [15], a 24-pulse rectifier is proposed which shows THD value of 5.20% at light load but fails to achieve the requirements of IEEE 519-1992 standard and shows large amount of fluctuation of THD from light load to full load. Another 24-pulse AC-DC converter designed in [16] has a THD value of 5.85% at 20% of the full load which also does not follow the IEEE 519-1992 standard. On the other hand this article utilizes the conventional 24-pulse parallelly connected rectifiers and by using a special interphase reactor (SIPR) with two additional power diodes we evolved that rectifier into 48-pulse rectifier resulting a THD of 3.55% at full load and 3.60% THD at light load. Both of the THD values of our proposed design can meet the requirements of IEEE 519-1992 standard.

This article is classified into five sections. In second section design of the proposed rectifier scheme and transformer connection with proper equation of turns ratio is described. Third section explains the simulation process of the proposed circuit, results are given in section four. At last, section five consists of conclusion with future works.

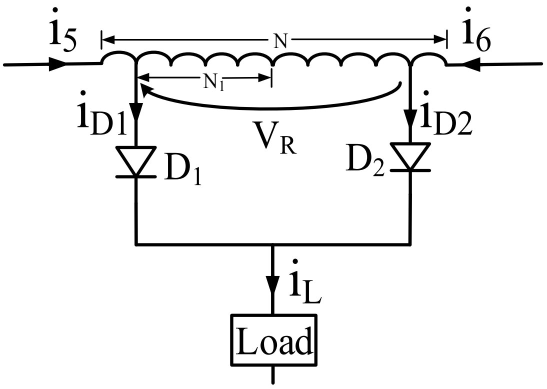

Fig. 1. Circuit configuration of the proposed SIPR.

Proposed 48-pulse rectifier

Figure 2 shows the proposed 48-pulse rectifier circuit. There are four zigzag phase shifting transformers, each of those transformers are connected to three pairs of power diodes. Each zigzag transformer associated with six power diodes forms a 6-pulse diode rectifier. Zigzag transformer of rectifier-1 is -15^o phase shifted. Similarly zigzag transformers of rectifier-2, rectifier-3 and rectifier-4 are 0^o, $+30^o$ and $+15^o$ phase shifted respectively. The proposed passive current injection circuit consists of two power diodes which are connected to the special interphase reactor (SIPR) showed in Figure 1. This SIPR worked as a pulse doubling circuit unit to convert the 24-pulse rectifier into 48-pulse rectifier. The load is connected to 24-pulse rectifier through the SIPR. For ensuring parallel operation two interphase transformers (IPT) are used in our proposed circuit configuration. As 30° phase shifting needed for our desired operation so, 0° phase shifting transformer associated rectifier 2 and +30° phase shifting transformer associated rectifier 3 is connected with IPT-1 while -15° phase shifting transformer associated rectifier 1 and +15° phase shifting transformer associated rectifier 4 is connected with IPT-2. Where requirements of the conventional 48-pulse rectifier is 48 power diodes and eight costly phase shifting transformers, the proposed 48-pulse rectifier unit needed only 26 diodes and the number of isolated transformer is four with addition of two IPTs and a SIPR. The proposed scheme can be used in high-power applications without any need of ac filters because harmonic distortion content on the AC input side is very low.

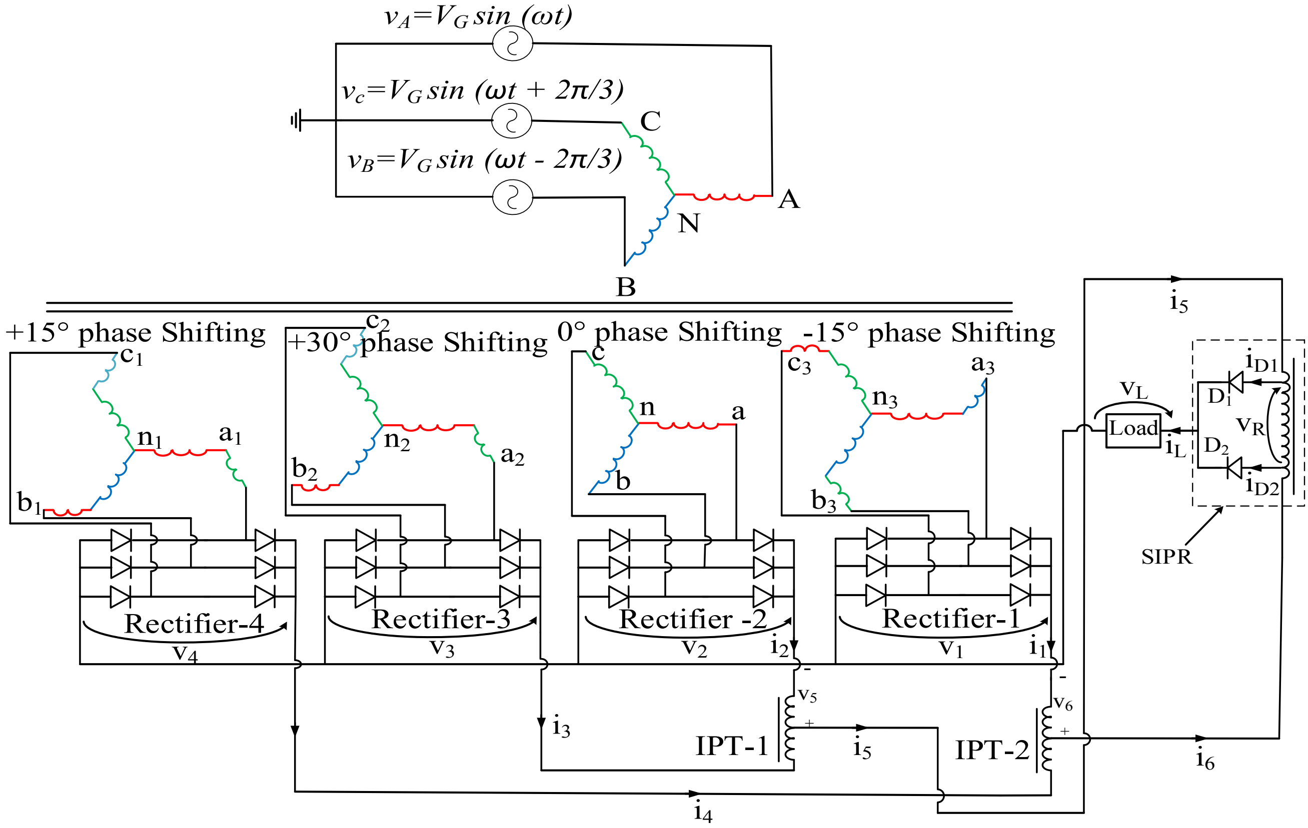

Fig. 2. Circuit configuration of the proposed 48-pulse rectifier circuit.

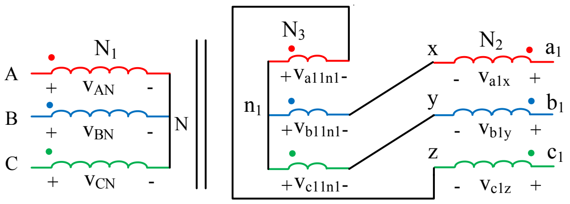

Fig. 3. Connection diagram of +15° phase shifting transformer.

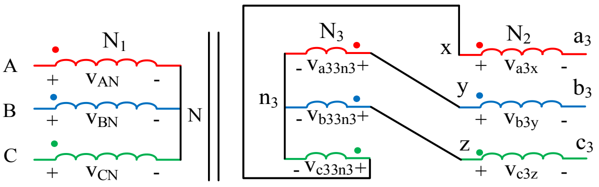

Fig. 4. Connection diagram of -15° phase shifting transformer.

Transformer connection

From Figure 2 it can be clearly seen that the proposed rectifier scheme employs four zigzag phase shifting transformers. Connection diagram of +15° phase shifting transformer is shown in Figure 3 which is similar to +30° phase shifting zigzag transformer's connection diagram. In Figure 4 connection diagram of -15° phase shifting transformer is shown. Phasor diagram of +15° phase shifting zigzag transformer is shown in Figure 5.

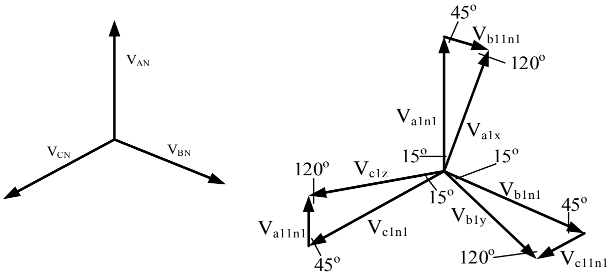

Fig. 5. Phasor diagram of +15° phase shifting zigzag transformer.

From the phasor diagram drawn at Figure 5 the following equation can be written:

$$\frac{V_{a1n1}}{\sin 120^\circ} = \frac{V_{a1x}}{\sin 45^\circ} = \frac{V_{b11n1}}{\sin 15^\circ} \qquad (1)$$

Voltage of a1x coil is V_{a1x} and turns number is N_2. Voltage of b11n1 coil is V_{b11n1} and turns number is N_3. Line voltages of primary and secondary side of the transformer are assumed to be equal valued so that turns number of a1n1 coil is equivalent to N_1. Turns number is substituted instead of voltage in (1) and the resultant turns number found is given in (3).

$$\frac{N_1}{\sin 120^\circ} = \frac{N_2}{\sin 45^\circ} = \frac{N_3}{\sin 15^\circ} \tag{2}$$

$$\begin{cases} N_2 = 0.816 N_1 \\ N_3 = 0.298 N_1 \end{cases} \tag{3}$$

Similarly the turns number for +30° and -15° can be equated and shown in (4) and (5) respectively.

$$\begin{cases} N_2 = 0.577 N_1 \\ N_3 = 0.577 N_1 \end{cases} \tag{4}$$

$$\begin{cases} N_2 = 0.816 N_1 \\ N_3 = 0.298 N_1 \end{cases} \tag{5}$$

Simulation and results

MATLAB software was used as a simulation tool to design our proposed 48-pulse rectifier. In Table 1 system specification having some optimal values are given. Using those values the simulation was done properly. Simulation design of MATLAB is given at Figure 6 in which each rectifier unit block consists of six diodes and two other diodes are connected to a multi winding transformer which act as an SIPR.

Table 1. System Specification

Parameters	Value
Input Voltage line-line (rms)	400 V
Source frequency	50 Hz
Turns ratio of the transformers	400:1
Rated Output	160 kW
Optimal tap ratio of the SIPR	0.249

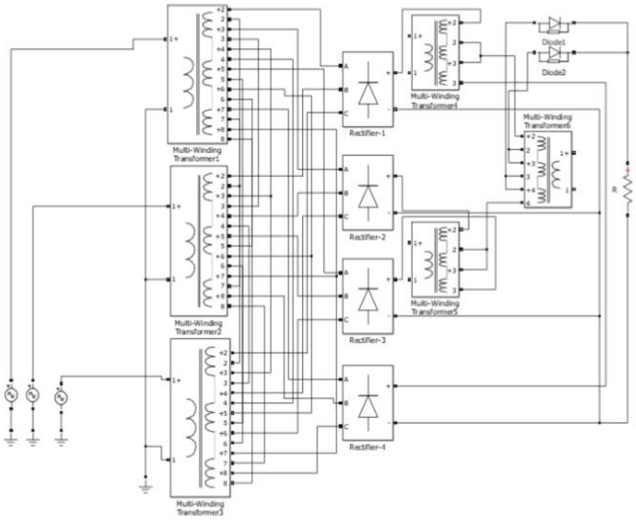

Fig. 6. MATLAB simulink model of the proposed 48-pulse rectifier.

Simulation was done by designing the model which is drawn in Figure 6 in the previous section. Figure 7 and Figure 8 shows input line current and FFT spectrum of the input line current at full load respectively. THD of the input line current is found 3.55% at full load which fulfills IEEE 519-1992 standard and this rectifier eliminates lower than 47^{th} order harmonics from the line current. In Figure 9 the output voltage curve of the proposed rectifier circuit is shown which contains 48 pulses in one cycle of the input supply voltage. For visualizing the THD performance of the proposed rectifier scheme Figure 10 is developed from which we can see that our proposed rectifier has an almost straight line curve hence it can be designated as a stabilized THD device. A comparison is given in Table II where different such types of schemes with respect to THD at varying loads are compared. By Table 2 we can see our proposed 48-pulse rectifier scheme has a THD fluctuation of 1.40% with respect to full load which is lower than all the compared schemes.

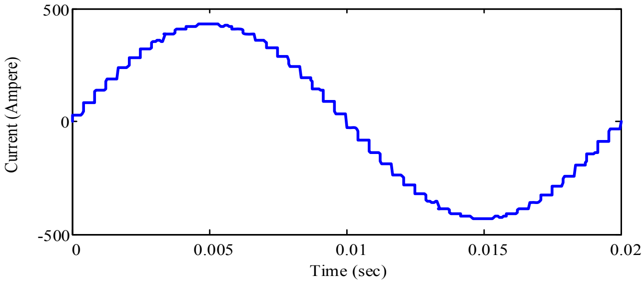

Fig. 7. AC input line current curve.

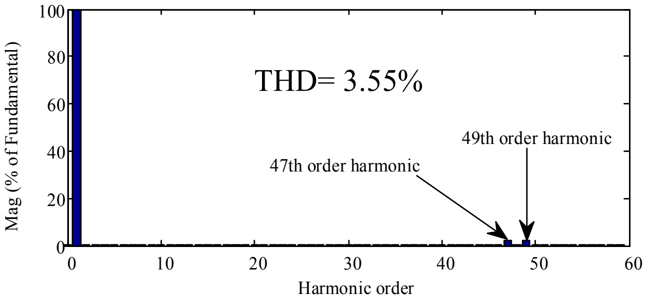

Fig. 8. FFT spectrum of the line current.

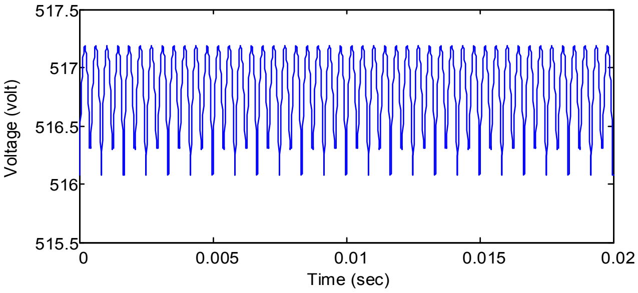

Fig. 9. Output voltage curve of the proposed rectifier.

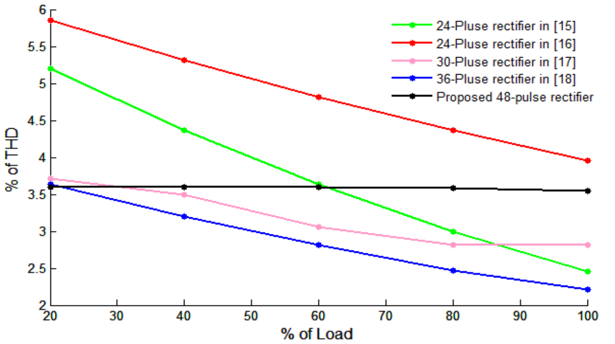

Fig. 10. % of THD vs. % of load curve to compare different rectifier circuit.

Table 2. THD comparison table

Topology	Number of pulses	THD of input AC line current at full load	THD of input AC line current at light load	THD fluctuation in terms of full load
R Abdollahi in [16]	24	3.95%	5.85%	54.29%
B. Singh *et al.* [17]	30	2.63%	3.71%	41.06%

Topology	Number of pulses	THD of input AC line current at full load	THD of input AC line current at light load	THD fluctuation in terms of full load
R Abdollahi in [18]	36	2.21%	3.64%	74.67%
R Abdollahi *et al.* [19]	40	2.55%	3.79%	48.63%
Proposed	48	3.55%	3.60%	1.40%

Conclusion

According to IEEE 519-1992 standard THD value must be less than 5% which is fulfilled by the proposed 48-pulse rectifier circuit in both full load and light load (20% of the full load) condition. From Table 2 it is clear that the proposed 48-pulse rectifier has a THD value of 3.55% at full load and 3.60% at 20% of full load. So, the difference between the values of THDs from light load to full load condition is very low and the fluctuation of THD with respect to full load is 1.40%. In others comparative schemes either the THD value is above 5% or the fluctuation of THD is very high. Though the number of electronic components, costly phase shifting transformers, IPTs and SIPR can be the effective loss parameters for calculating efficiency of the proposed system but design simplicity, THD stability and ease of use makes it suitable to operate as a reliable device for harmonic mitigation. Extension of this work can be done by designing higher pulsed (60-pulse, 72-pulse etc.) rectifiers for better performance and making a laboratory prototype of the proposed rectifier system. This multipulse rectifier is applicable to electrochemical and electromechanical systems, variable load applications, adjustable speed drives etc.

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