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Performance Evaluation of Varying Triggering Angles on Single-Phase Semi-Bridge Controlled AC-DC Converter

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Abstract. This paper presents performance evaluation of varying triggering angles on single-phase semi bridge controlled AC-DC Converter, which are, dependent on the deferment angles. This article is meant for adequately identifying the better range of deferment or delay angles for controlled rectification for optimal performance of the single-phase half wave AC–to-DC converter. The single-phase half wave controlled rectifier is formed by combination of thyristor power switch, power cables and triggering circuit in the presence of supply voltage and the load/s. This article is also used to find out the levels of total harmonic distortions, amplitudes and the nature of the output voltage of single-phase half bridge controlled rectifier at varying firing angles. It also presented the clear convenient range of firing angles to be used for AC-DC rectified based appliances that have not been shown in other work done online in this perspective. The overall system is modeled and simulated in MatLab 2018. The outcomes of the investigations are that: (i) the best operating ranges of triggering actions occurred after delay angles of 15^o and 30^o , (ii) the output voltage or current of the rectifier after delay angles of 15^o and 30^o needs small size of filter components , (iii) the proposed system has low harmonic distortions after delay angles of 15^o and 30^o (iv) at delay angle of 180^o, the output of the system turned in complete AC waveform that are detrimental to connecting it directly to DC loads, hence complete avoidance of operating after delay angle of 180^o.

Keywords. AC-DC, effects, evaluation, triggering angles, single-phase, semi-bridge

1. Introduction

AC-DC converter is the only converter that has direct linkage between AC power and DC power. It is a power electronics device that converts AC power that changes periodically to DC power under unidirectional current flow[1]. It is just opposite of power inverter in operations. It can be controlled or uncontrolled converter [2]. When it

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is uncontrolled, the rectifying component to perform the action is the diode. And under controlled mode, the rectifying components could be thyristor (phase controlled) or Mosfets/ IGBTs (pulse width modulated controlled) [3-4]. There are several applications of AC-DC converters ranging from DC Motor controlled speed, battery charger, AC-DC power supplies, improving the power quality of aircraft, high voltage direct current transmissions, AC fed traction system, electrochemical processes, reactor control, DC motor drives, electro-chemical/electro-metallurgical process , magnetic power supplies, controlling reactor, driving portable hand tools, variable speed industrial drives, uninterruptible power supply system, etc. [4-5]. The main problems of thyristors based AC-DC converts are the issue of harmonics and low power qualities [5]. The setback associated with harmonics and low power factor are minimized by increasing the number of pulses (multiphase AC-DC converters such as 6-pulse, 12-pulse, 18-pulse, 24-pulse, 36-pulse, 48-pulse) [6-7] and applications of filter components (both active and passive types) and they have been addressed and published online by many authors[8-10].

However, when the numbers of components are increased by those multi-pulse configurations, there is guarantee of enormous power losses, complex power and control circuitries or component count, high systems cost of production, low market turn up and space occupancy. In order to reduce the issues just mentioned characteristics of multiphase AC-DC system in small scale and medium power applications, this paper gears towards using the single pulse controlled AC-DC converter. In this research work, it is meant to investigate and to come up with better operating range of firing angles at constant 50% pulse-width and at varying firing angles. The idea is to find out the convenient range of firing angles to be used for AC-DC rectified based appliances and also to minimize the rate of total harmonics in single-phase half bridge controlled rectifier for small and medium scale industrial applications without using filtering components. Another unique work that has been done in this research is application incidence matrix current scheme in analyzing current flow in the entire circuit that is not seen in the related thyristor controlled system.

2. Methodology

MatLab/Simulink modelling, simulation and experimentation are adopted in this research work.

Figure 1 is the system that is used in this research work. It consists of AC voltage supply, Vs, thyristor switch, Th, pulse width modulation (PWM) scheme, load, L (resistive load) copper cables and feedback system.

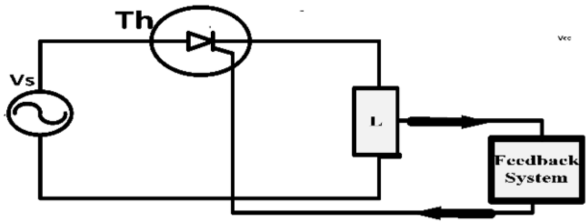

Figure 1. Proposed research system [1-4]

When the delay angle is ON and during positive half cycle, the current flows from the source to the load. And, the current direction under this condition, is described as in equation (1) using incidence matrix analysis that is based on zero, positive one (1) and negative one (-1) scheme

$$i_{nb} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 1 & 0 \\ 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 \end{bmatrix} \quad (1)$$

Where n and b represent the nodes/load/source, where two or more wires are met and the branches where current flows

As soon as delay angle is OFF and during negative half cycle, the current ceases from the source to feed the load. And, the current movement under this condition, is described as in equation (2).

$$i_{jk} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (2)$$

The average voltage, root mean square voltage, average current and root mean square current load [1] are expressed as in equations 3 - 5

$$v_L = 2V_{\max} \cos^2\left(\frac{\alpha}{2}\right) - 1 \quad (3)$$

$$v_{rms} = V_{\max}\sqrt{\frac{\pi-\alpha}{4\pi} + \frac{2\sin\alpha\cos\alpha}{8\pi}} \quad (4)$$

$$I_L = \frac{2V_{\max} \cos^2\left(\frac{\alpha}{2}\right) - 1}{R} \quad (5)$$

$$I_{rms} = \frac{V_{\max}}{R}\left[\frac{\pi-\alpha}{4\pi} + \frac{2\sin\alpha\cos\alpha}{8\pi}\right] \quad (6)$$

V_{max}-peak voltage, R-load resistance, α -delay angle.

3. Total Harmonic Distortion

Conventionally, current and voltage of total harmonic distortions of power converters and other related systems are calculated using the expressions in equations (15) and (16) as ready in [1].

$$THD\left(for \quad current\right) = \frac{\sqrt{\sum_{n=2}^{\infty} i_n^2}}{i_n} \quad (7)$$

$$THD\left(for \quad voltage \right) = \frac{\sqrt{\sum_{n=2}^{\infty} v_n^2}}{v_n} \tag{8}$$

I_n and V_n are amplitude harmonic components of current, I_1 and voltage V_1.

The calculation of total harmonic distortion of current and voltage waveforms using equations (7) and (8) is an estimated method. It is likewise so burdensome, demanding and time- consuming method. And due to those reasons, we employed power graphic user interface (PGUI) Format resident in MatLab/Simulink environment. It is non-time consuming method, accurate and better than using equations (7) and (8).

4. Pgui Procedures

Step. I: Develop the Simulink model of the proposed system of your choice. Step. II: Pick up the pgui block from the Simulink Library. Step. III: click on the workspace block twice. Then, click on the 'parameters' within the workspace once. Besides, click also on "History" and adjust its "Format" to be in Structure with time". Finally, Click "OK" Step. IV: Run or simulate your proposed system Step. V: click on PGUI block twice, it displays "simulation and configuration Options" or "Block parameters" depending on the version of MatLab/Simulink software, you are using. Step.5: single click on "Tool" followed by "FFT analysis", it displays four sub-sections: signal section, FFT analysis section, available signal section and FFT setting section. Step.6: Finally, click on display button, the FFT analysis section, shows the total harmonic distortion level of the output wave in percentage value and in bar chart form.

5. Simulation Results and Discussion

Figure 2 illustrated controlled rectified output voltage and current that operated at a delay angle of 15° and the corresponding switching pulses. This implies that some portions of the voltage and current were not meant for feeding the load connected to it. It is observed that rectified voltage, rectified current and pulses have 311V, 3.5A and 1.0V respectively.

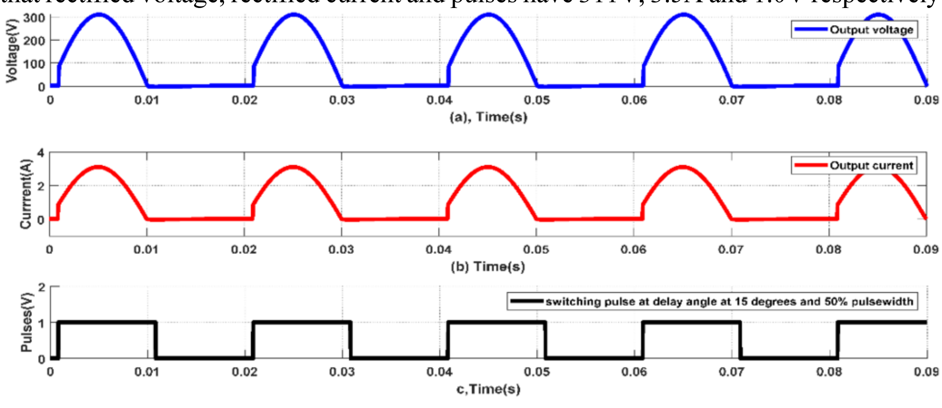

Figure 2. (a) Controlled rectified voltage, (b)Controlled rectified current, (c)Switching Pulses at delay angle of 15°

The harmonics spectral analysis of voltage at firing angle of 15° is displayed in figure 3. It is noticed that the under 15° delayed angle, the percentage of total harmonic distortions (THD) and active participating DC voltage were 46.85% and 154.4V

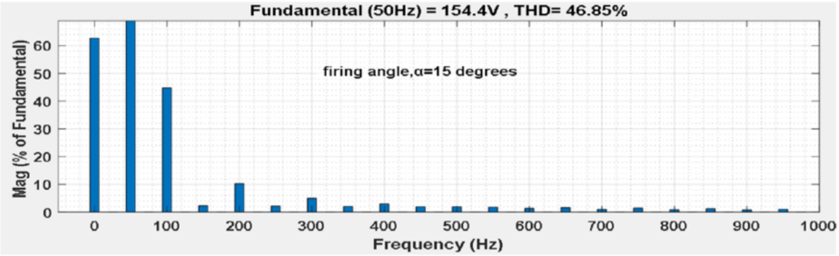

Figure 3. Harmonics spectral analysis of voltage at delay angle of 15°

In figure 4, the rectified voltage and rectified current with their corresponding pulses were shown. It is detected their waveforms resembled figure 2 except that the area covered after 30° delay angle decreases but their corresponding THD in figure 5 increased.

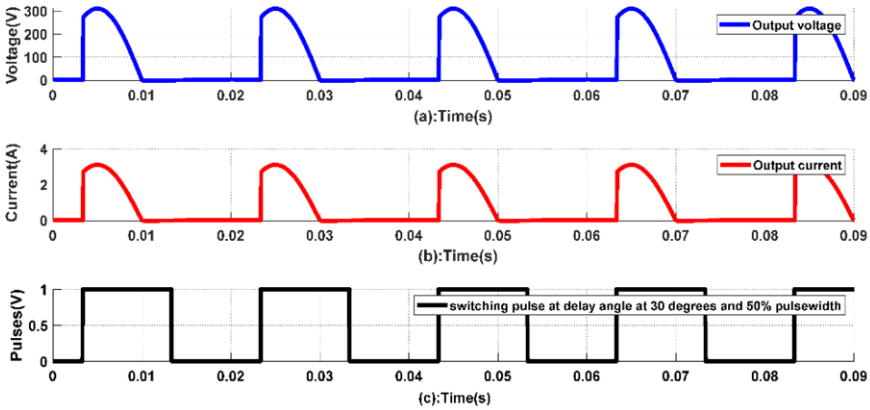

Figure 4. (a)Regulated rectified voltage, (b)Regulated rectified current, (c) Switching Pulses at delay angle of 30°.

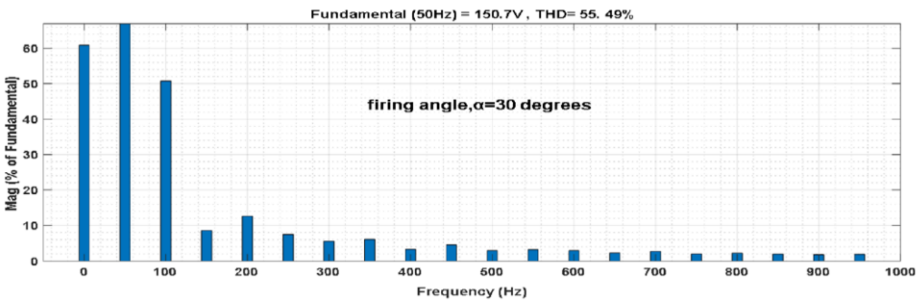

Figure 5. Harmonics spectral analysis of voltage at delay angle of 30°

Figure 6 demonstrated regulated-rectified output voltage and current that were activated after a delay angle of 45° and the corresponding switching pulses. It is observed that the rectified voltage, rectified current and pulses have 311V, 3.5A and 1.0V respectively.

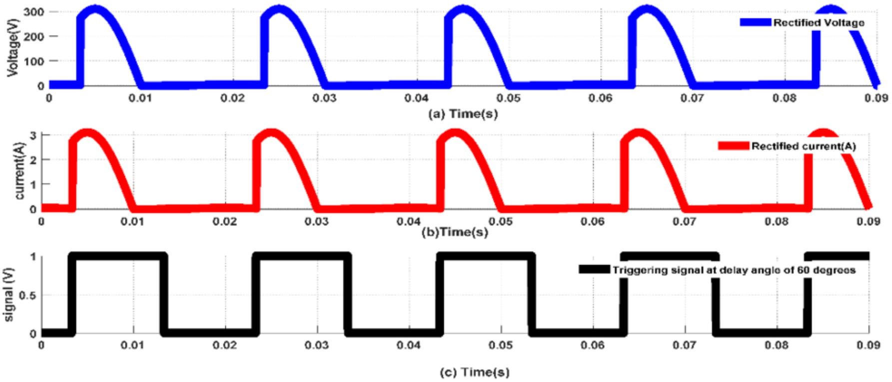

Figure 6. (a)Controlled rectified voltage, (b)Controlled rectified current, (c)Switching Pulses at delay angle of 45°.

Figure 7 reported the spectral analysis of total harmonic distortion of the output voltage under resistive load. Besides the active participated DC voltage component and the total harmonic distortion are 142.7V and 66.62% respectively

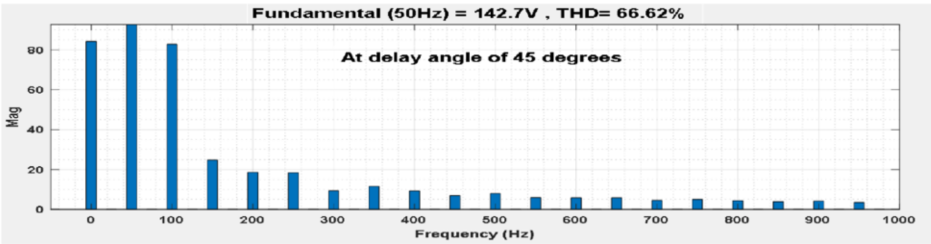

Figure 7. Spectral analysis of total harmonic distortion of the output voltage

The voltage harmonics spectral analysis was displayed in figure 8. Moreover, at fundamental frequency 50Hz, it was noticed that the THD of the actively participated rectified voltage of 129.1V was 80.55%.

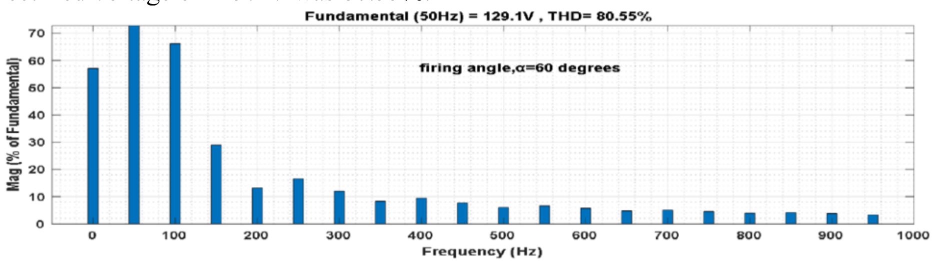

Figure 8. Harmonics spectral analysis of voltage at 60° delay angle

The rectified output waveforms of the proposed system were shown in figure 9(a-b) and their pulses at 90° delay angle was represented in figure 9(c). Moreover, it is observed that as the delay angle increased, graphically, the area covered by rectified output waveform decreased.

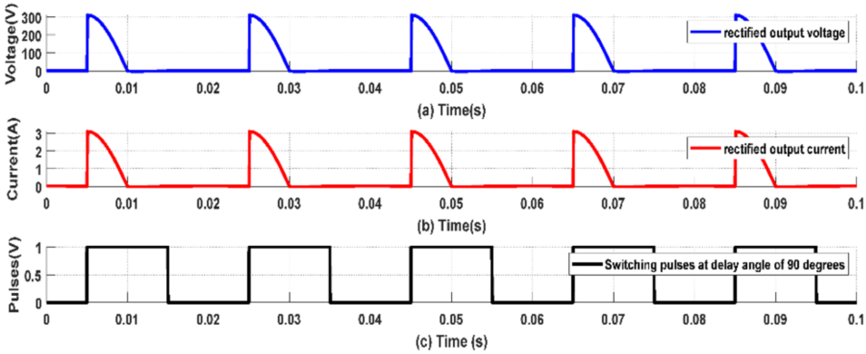

Figure 9. (a)Controlled rectified voltage, (b)Controlled rectified current, (c)Switching Pulses at delay angle of 90°

The total harmonic distortion of figure 8(a) is shown in figure 10. At the delay angle of 90°, the voltage THD and actively participated DC voltage were is 114.27% and 90.6V.

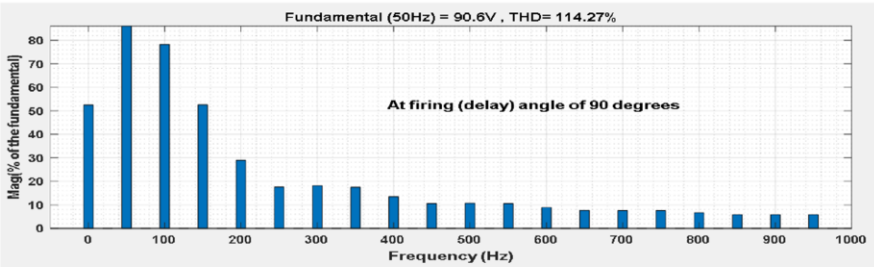

Figure 10. (a)Controlled rectified voltage,(b)Controlled rectified current, (c)Switching Pulses at delay angle of 180°.

Figure 11 described the statistical analysis of the proposed investigated system. It is observed that figure 11(a) and figure 11(d) showed histogramic plots of voltage and current which correspond to figure 2(a) and figure 2(b) in terms of amplitudes. Figure 2(c) and figure 2(d) illustrated the demonstration of conductance and resistivity under resistive load.

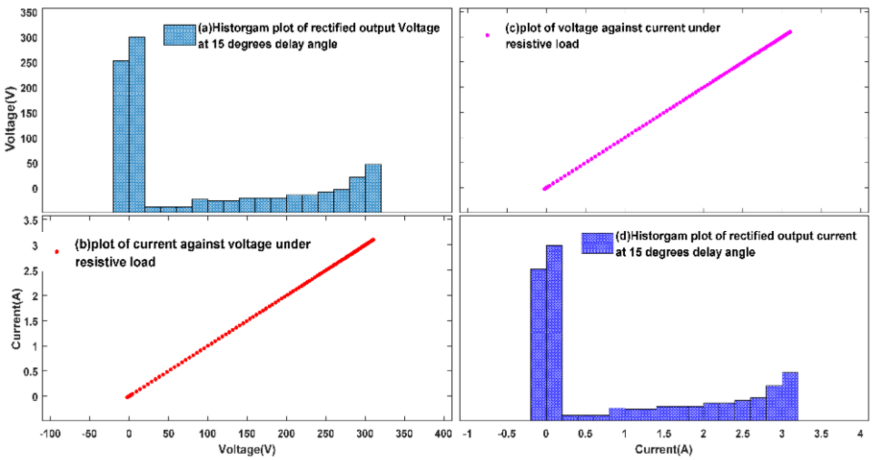

Figure 11. Statistical plot of proposed investigated system

6. Experimental Results and Discussion

Figure 12-18 displayed the experimental results of the proposed investigated system. Figure 18 showed the Laboratory set-up with an oscilloscopic display the rectified output voltage of the system with the switching pulses after a delay angle of 15°. It is observed that it resembled waveform of figure 2(a) and figure 2(c).

Figure 12. Experimental Set of the proposed system at delay angle of 15°

Figure 13 displayed an oscilloscopic display of a rectified output voltage of the system with the switching pulses after a delay angle of 30°.

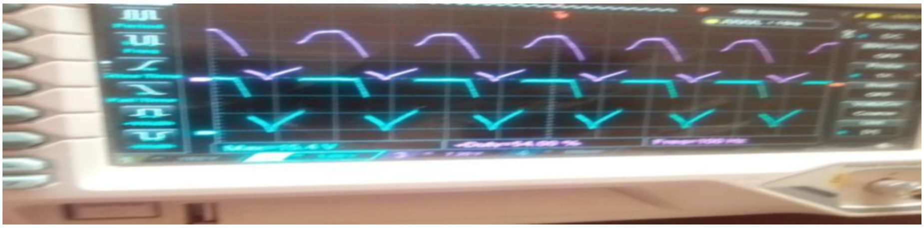

Figure 13. Experimented rectified output voltage and switching pulses at delay angle of 30°.

Figure 14 presented an oscilloscopic show of a rectified output voltage of the system with the triggering pulses after a delay angle of 45°.

Figure 14. Rectified output voltage and switching angle of 45°

A rectified output voltage of the system with the switching pulses after a delay angle of 90° was illustrated in figure 15.

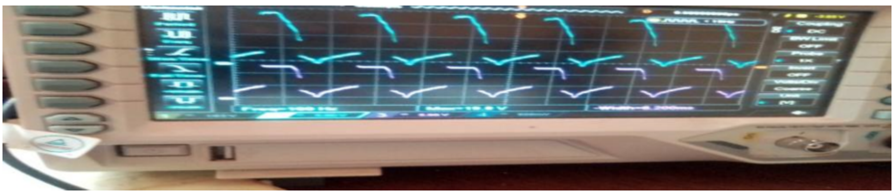

Figure 15. Rectified output voltage &switching pulses delay angle of 90°

Figure 16 illustrated an oscilloscopic display of a rectified output voltage of the system with the switching pulses after a delay angle of 120^o.

Figure 16. Rectified output voltage and switching angle of 120^o

Figure 17 demonstrated an oscilloscopic display of a rectified output voltage of the system with the switching pulses after a delay angle of 150^o.

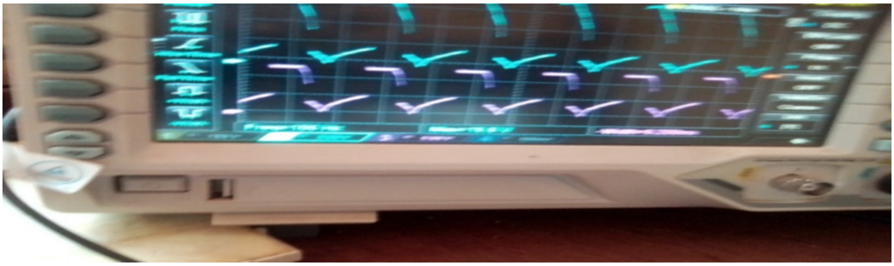

Figure 17. Rectified output voltage and switching angle of 150^o

Figure 18 showed an oscilloscopic display of a rectified output voltage of the system with the switching pulses after a delay angle of 180^o. It is clearly showed that after, a delay angle of 180 degrees during the controlled half-wave rectification as illustrated in figure 18, a complete AC voltage waveform with reduced amplitude appeared. The waveform is very dangerous to feed any DC load directly.

Figure 18. Rectified output voltage and switching angle of 180^o

Table 1 showed tubular outcomes of the investigated performance characteristics of the proposed system. It indicated that the delay angle, $\boldsymbol{\alpha}$, of the proposed system, operating at this interval, 0 <$\boldsymbol{\alpha}$≤30^o, has good DC power applications with low filter components to filter the THD, low total harmonic distortions and small required filter components. It also observed that the at 180^o delay angle during the reification, the output waveform turned completely into AC component with reduced amplitude. This implies that it is not good to be operating that region as far as DC application is concerned.

Table 1. Performance characteristics of the proposed system.

Fundamental frequency(Hz)	Delay angle(°) α	THD%	Conduction angle(°)	Filter component' requirement	Active participating DC voltage(V)	DC application
50.00	15.00	46.85	165.00	Low	154.40	Very high
50.00	30.00	56.49	150.00	Low	150.70	Very high
50.00	45.00	66.62	135.00	High	142.70	High
50.00	60.00	80.55	120.00	High	129.10	High
50.00	90.00	114.27	80.00	High	90.60	Low
50.00	120.00	168.31	60.00	Very high	45.10	Low
50.00	150.00	311.44	3.000	Very high	10.58	Very Low
50.00	179.00	4.75	1.00	Negligible	Absolute 2.43	Rarely Used
50.00	180.00	0.004	0.00	None	0.00	None

7. Conclusion

The performance evaluation of varying triggering angles on single- phase semi-bridge controlled AC-DC converter has been presented in this research work. And the following results were obtained: THD of 46.85%, 56.49%, 66.62%, 80.55%, 114.27%, 168.31%, 311.44%, 4.75% and 0.004%; DC components of 154.40 V, 150.70 V, 142.70 V, 129.10 V, 90.60 V, 45.10 V, 10.58 V, Absolute 2.43 V and 0.00V at delay angles of 15°. 30°, 45°, 60°, 90° , 120°, 150°, 179° and 180° respectively. One of vital benefits of this research is that no DC appliances will be connected at delay angle of 180° respectively. The idea is to avoid damaging the DC-based appliances. Moreover, the practical waveforms and the simulated waveforms are closely related. The importance of this research is to enable us to know the range of delay angles to operate with the proposed system to save the lifespan of our DC purely related appliances connected to rectifier directly.

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