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The Effects of Total Harmonics Distortion for Power Factor Correction at Non-Linear Load

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ABSTRACT

This paper presents the effect of total harmonic distortion (THD) in power factor correction (PFC) at non-linear load. This study focuses on the relationship between THD and PFC. This is beacuse, the power factor affects THD. This occurs in power system as we have variety of loads, i. e linear load or non-linear load. The variety of loads will influence the sinusoidal waveform, which comes out from harmonic distortion. Thus, based on this study, we can compare the effective method in improving the power factor as it will not disturb the performance of THD. The focus of study is on the single phase load, where the voltage restriction is 240 V. The analysis will only focus on the consumer, which depends on the variety of non-linear load. Besides, the parameters for analysis are based on the percentage of THD and the value of power factor. The instrument for measuring the parameter is based on power factor correction device or technique. On the other hand, the method that was used for this study is based on simulation which incorporated the Multisim software. At the end of ths study, we can choose the most effective method that can be used to improve the power factor correction without disturbing the THD.

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1. INTRODUCTION

This study focuses on the effect of total harmonics distortion in power factor correction at a non-linear load. By definition, power factor correction is a technique that is opted to minise the amount of reactive power as a measure to balance the power factor. The components at a non-linear load are able to influence the power factor value which is triggered by the components such as the inductor or capacitor. The tenants will be penalized if the power factor reading does not tally with the rated reading provided by the Suruhanjaya Tenaga, Tenaga Nasional Berhad (TNB) [1]. The purpose of this study is to investigate the total harmonics distortion based on the various techniques of *power factor correction* at non-linear load. Besides that, the most effective method of power factor correction that will not disturb or disrupt the total harmonics distortion will be proposed in this work as well.The total harmonic distortion (THD) is the total voltage ratio divided by the current harmonic to the fundamental voltage /current harmonic. All the values are dependant on the harmonic fundamental value. If the value of THD is larger than 1%, it denotes that the load contains a low quality power. The formula to calculate the percent of THD is shown in [2]:

$$THD = \frac{\sqrt{V_2^2+V_3^2+V_4^2+V_n^2}}{V_1} \tag{1}$$

To date, there are various methods used to measure power quality in the power system. One of the methods is by measuring power factor. A low power factor denotes that the power quality is poor. Infact, a low quality of power may have a negative impact either on the power management of Energy Company (Tenaga Nasional in the case of Malaysia which is normally known as TNB), the consumer or to the load. Based on the TNB, if the power factor value is less than 0.9 (for electricity supply 132kV and above) and less than 0.85 (electricity supply below 132 kV), a surcharge will be imposed on the consumer [1].

Theoretically, an ideal power factor is described as unity or one however in a real application system, it is impossible to have power factor at unity since it has distributed losses in the production process. Thus, at juncture when the value of power factor is less than one, it shows that there is a problem with the apparent power. This because the reduction of apparent power is triggered by the losses in the reactive power whereby in the real process, it is necessary to provide a magnetising field. This is required by motors or other inductive loads in order to perform the functions. On the other hand, the power factor is regarded as poor if there is a differencw in the significant phase between the voltage and current at the terminals load which is known as the harmonic distortion. A high harmonic content in waveform will give impact to the power factor value. The examples of common inductive loads include the induction motor, a power transformer, ballast in a luminaire, a welding set or an induction furnace. A distortion that occurs in a current waveform can be created by using a rectifier, an inverter, a variable speed drive, a switched mode power supply, discharge lighting or other available electronic loads.

Inductive loads contribute to a poor Power Factor Correction. As a remedy for the problem, power factor correction equipment needs to be addded into the power system. In addition to this, harmonic filter must be introduced in the circuit in order to rectify any distorted current waveform which tends to reduce the power factor value. Even though the inverters are usually claimed to have a relatively high power factor value (>0.95), the theory is only valid when the waveform current is inconsistent and only involves the angle calculation between the voltage and current. In fact, a real value of power factor in reality is around 0.5 to 0.75. In general, there are two different methods of Power Factor Correction which are known as the passive components and the active components. Power Factor Correction (PFC) operates by reducing the harmonic distortion and increases the real power level value during the operation. To add on, the value of real power level can be increased simply by improving the current shape input. The Linear load, i. e purely resistive load is the most ideal tool in minimizing the losses as compared to the reactive load. This is because the reactive load may have an erroneous power supply switching. Besides that, the low power factor can be compensated by using either passive or active devices. Electrical motor is the most convenient example to represent the load that is needed to improvise the power factor, since it is known as having the highest inductive load with the availability of loads. The amendment would be to use the capacitors to counter the circuit. However, it can be quite a challenge to rectify the entire system as many circuit designers need to take into consideration about the matter by not introducing any resonant into the system. Furthermore, an adaptive scheme connected to the reactive elements need to be implemented to the variable power factor and to the high powered machinery. At this juncture, it is also important to take into consideration of the component's cost, space and efficiency in accommodating the specific power rating.

A passive component such as diode is used in the converter for the passive power factor improvement. In this case, the converter is a bridge rectifier, in which the device functions in converting the alternating current signal either voltage or current signal to direct current signal [4]. Theoretically, by using this approach, the power factor can be increased to a value of 0.7 to 0.8. By increasing the input voltage value, the power factor values' will become higher. The function of a passive power factor improvement is similar to a low pass filter, in which it will filter out all the harmonic contents in the circuit. However, the passive power improvement can only be improvised within a range of 0.7 and 0.8 value. The value should not exceed 1.0 as it can decrease the wave current within the standard. An active power factor improvement is an innovation from passive power factor improvement. An active approach is an excellent way to improve the power factor correction in electronics appliance. This design is aimed to control the amount of power produced from the loads and obtained as the value of power factor is close to unity. The active components control the current input of the loads which are similar to the waveform voltage (perfect sin wave) [9]. Besides, the components can reduce the content of harmonic and distortion by combining the reactive elements or using active switches such as Mosfet, Control IC and others. Table 1 summarizes the alternatives for active and passive power rectification.

Table 1. Methods that can be used in active and passive power correction methods

No	Methods	Description
1.	Conventional boost converter	i. Contain a rectifier circuit and boost converter. See Figure 1. ii. Excellent for low and medium power range loads iii. Disadvantages: The size and volume of inductor. This is because in electronics circuit should not be too heavy [6]
2.	Bridgeless boost converter	i. There is no rectifier circuit and the solution for power level is greater than 1Kw. See Figure 2. ii. It solves the disadvantages of conventional method but elevates the noise. The loss of conduction can be minised by paralleling the semiconductor components. iii. Disadvantages: The floating input line with respect to the PFC stage. The diode and MOSFET failed to identify the flow of current during each of half-line cycle [7].
3.	Interleaved boost converter	i. Consist of two Boost converters and both of them are connected in parallel as shown in Figure 2. ii. The current input is the total current flow throughout the two inductors. iii. Advantages: It is able to reduce the ripple in the current waveform and it indirectly reduces the total harmonics distortion or error especially in high frequency. Besides, it also minimise the conduction losses by paralleling the semiconductor components.

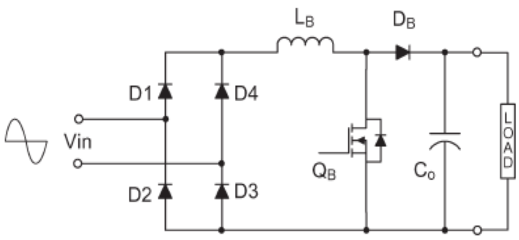

Figure 1. Conventional boost converter

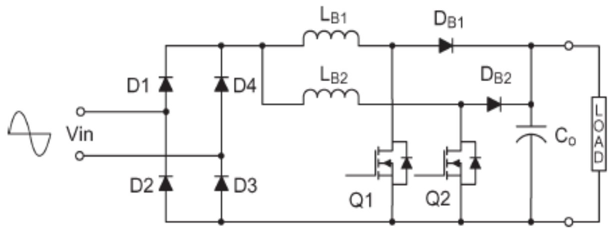

Figure 2. Bridgeless boost converter

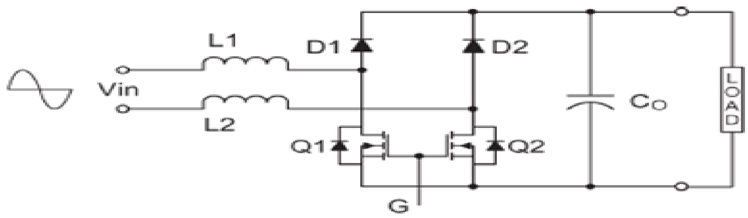

Figure 3. Interleaved boost converter

2 RESEARCH DESIGN

Figure 4 shows the process which is adapted in this paper for simulation purpose. In designing a circuit, there are five (5) stages that need to be considered. The first stage is, from the power source which enables electrically operated equipment to be connected to the alternating current (AC) in any premises or buildings. In status quo, the voltage will be exteremely high for electronics appliances inspite of the difference in connectors, shape or voltage and current rating of the electrical plugs. The second stage is known as the converter. The converter will change the alternating current (AC) source to direct current (DC) sources which is certifiably known as a rectifier [10]. In this stage, the rectifier will be changed under two (2) conditions where the first rectifier uses passive component and the second rectifier uses bridgeless topology. Stage three (3) is considered as a crucial stage in the simulation design as the filter is used to improvise the performance of the waveform and indirectly eliminate the ripple or distortion of the waveform. In stage four (4), the simulation circuit is incorporated with the boost circuit as a measure to produce the direct current

(DC) source value before it can be used in electronics appliances [11]. The last stage relies heavily on the load. At this stage, the non-linear load will be used.

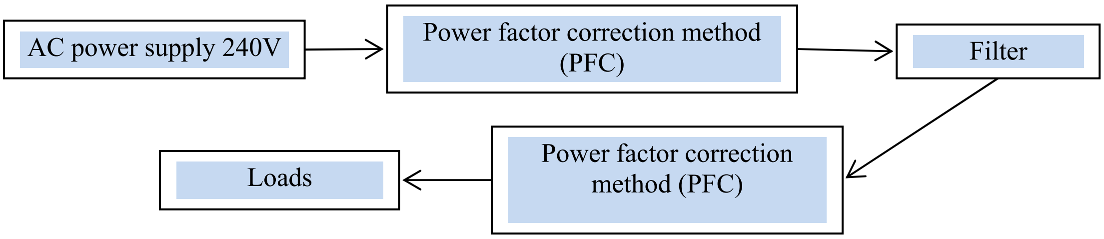

Figure 4. Block Diagram of simulation circuit

2.1 Power Factor Correction (PFC) by Using One Converter

2.1.1 Converter Using Passive Components

The method of the circuit is shown in Figure 5.

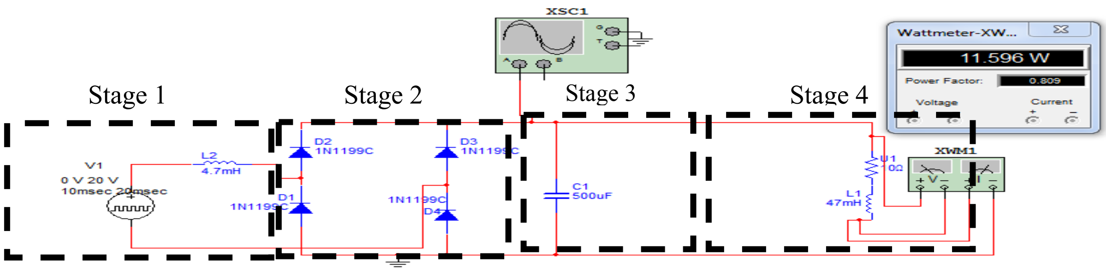

Figure 5. Equivalent circuit of Power factor Correction method (PFC)

Description of the circuit as shown in Figure 5 is as follows:

Stage 1:

1. Pulse voltage is used to create content of harmonic as well as for analysis of one complete cycle waveform.
2. Pulse voltage duration is set to 20ms since one period frequency is equivalent to 50Hz.
3. Voltage is ranging from 0 to 20V as a huge number of home electronics appliances use DC supply which ranges from 10V to 20V.

Stage 2:

1. Rectifier circuit is used to convert the Alternating Current (AC) sources to Direct Current (DC) sources. This converter is used since numerous electronics appliances are in need of DC supply. However, the socket outlet uses AC supply merely.
2. The bridge rectifier is an example of source that creates harmonics. The bridge in this circuit opts for passive components (uncontrolled full-wave rectifier) and it uses Power Factor Correction (PFC) to control the power factor flow at the load.

Stage 3:

1. Filter circuit of this stage is used to reduce the ripple of the waveform and the content of the harmonics.

Stage 4:

1. At this point, non-linear load creates the harmonics contents at the output value depending on the impedance.
2. In this circuit, the resistor and inductor is used at load to represent nonlinear load as the variable value of impedance is used to analyze the output result within the variable loads.

2.1.2 Converter Using Bridgeless Topology

The equivalent circuit of PFC is shown in Figure 6.

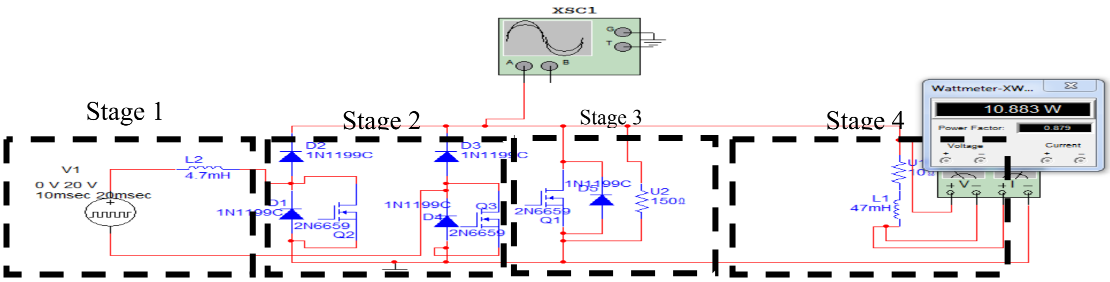

Figure 6. Equivalent circuit of Power Factor Correction Method (PFC)

2.2. Power Factor Correction (PFC) by Using Two Converter

2.2.1. Converter Using Bridgeless Topology And Boost Converter

The circuit is shown in Figure 7. Non-linear load creates the content of harmonics in the output value depending on the impedance.

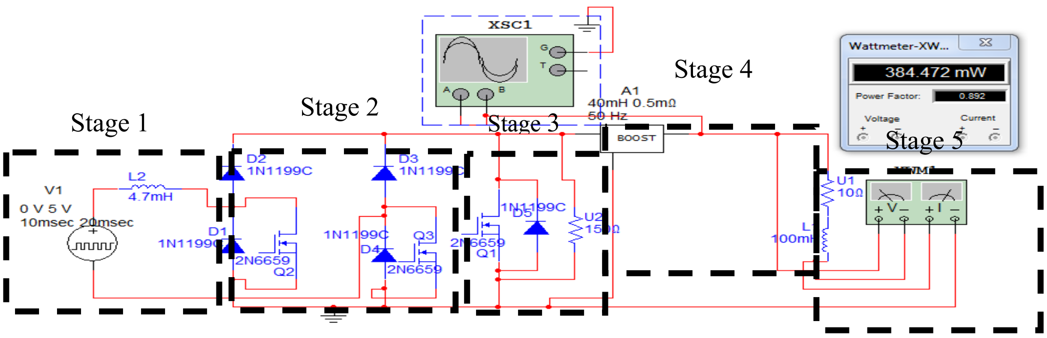

Figure 7. Equivalent circuit of Power Factor Correction method (PFC)

2.3. Power Factor Correction (PFC) by Using Two Active Converters

2.3.1. Converter Using Bridgeless Topology and Interleaved Converter

The circuit of this topology is given in Figure 8.

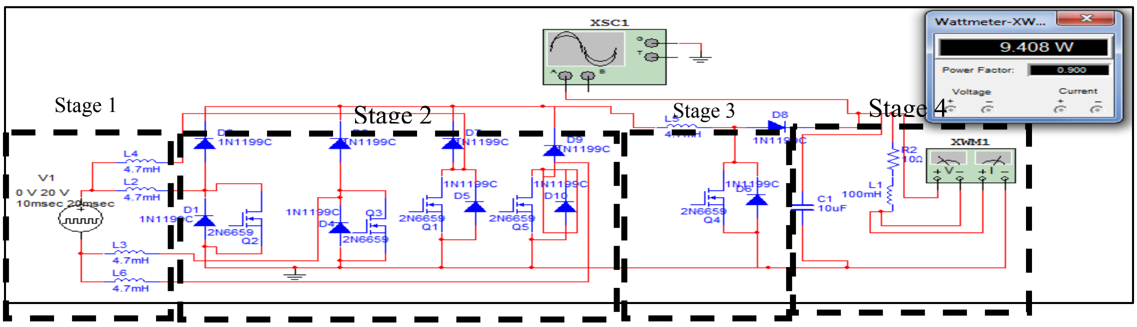

Figure 8. Equivalent circuit of Power Factor Correction method (PFC)

Stage 1:

1. The pulse voltage was used to create a harmonic content for the analysis of one complete cycle waveform.
2. Next, the duration of pulse voltage is set to 20ms due to the setting of one period frequency which is equivalent to 50Hz.
3. Voltage setting adheres to the earlier design.

4. The inductor functions as an input current sensing, which senses the current flow to the Bridgeless topology circuit.
5. The role of four inductors is to elevate the current flow from the input.

Stage 2:
1. Bridgeless topology is used as a power factor correction method and at the same time to create harmonics.
2. The function of parallel components between diode and MOSFET is to minimise the conduction loss during the switching mode [8].

Stage 3:
1. Interleaved topology is used to improve the amount of THD and to maintain the value of power factor.
2. Boost converter is used as a power factor correction device which increases the value of power factor. Thus, when the value of inductor (in boost converter circuit) differs, it will affect the power factor and total harmonic distortion values.

Stage 4:
1. Filter circuit in this stage is used to reduce the ripple of the waveform and the content of the harmonics.
2. The non-linear load will calculate the harmonics contents in the output value in relation to the impedance.

3 RESEARCH RESULTS AND ANALYSIS

In this section, the results of each methods are explained and presented. They are presented in sequences. Besides, the explanation for each finding is discussed to validate the data.

3.1. Power Factor Correction (PFC) by Using One Converter

3.1.1. Converter Using Passive Components

Table 2 refers to the summary of PFC method by using rectifier passive components converter. Based on the Table 2, when the reactance value is adjusted (resistor value fixed), the value of PFC is significantly higher and acceptable. However, when the reactance and resistor value fluctuates and elevates inconsistently the PFC value became low.

Table 2. Summary of PFC by using passive component rectifier

V_{in} (V)	load (resistor) ohm	load inductor (mH)	pfc	THD (%)
5	10	47	0.748	32.148
	10	100	0.919	33.616
	150	100	0.635	33.606
15	10	47	0.807	32.353
	10	100	0.672	33.162
	150	100	0.928	33.162
20	10	47	0.809	32.340
	10	100	0.762	33.095
	150	100	0.93	33.095

Theoretically, if the resistor value is small, the real power voltage will be small and vice versa. It will eventually affect the value of power factor. Nevertheless, if the value of resistor remains while the reactance value decreases, it will affect the value of reactive power. At this point, it is crucial to comprehend that apparent power is equal to the total of real power and reactive power which also suggest a way to control the power factor. An increase in the supply value will have an effect on the power factor. According to Ohms law, in order to calculate the power factor, the voltage value, current and load must be considered. For instance, the power factor is reduced when the voltage supply is adjusted from 5Vdc to 15 and 20V at the load R = 10Ω and L = 100mH.

3.1.2. Converter Using Bridgeless Topology

In this analysis, a rectifier circuit with two MOSFET is incorporated in this design. The function of the MOSFET components is to serve as a switching button for the rectifier circuit. During each cycle, one MOSFET operates as a switch to boost up the diode 1 and another MOSFET will operate similarly as ausual diode. The purpose of using this method is to reduce to conduction loss. Based on the Table 3, it can be concluded that the PFC values reading become lower when the reactance value is adjusted and resistor value is remained. Nevertheless, the THD reading has been significantly improved as compared to the previous method. Thus, based on the waveform output, it can also be seen that the ripple content has been eliminated, especially when the value of both reactance and resistor are extremely low. This is because bridgeless method reduces the noise of the waveform, hence producing a waveform without ripple. Nevertheless, an increase in the supply value may also have an effect on the power factor. Based on Ohm's Law, a high voltage value will result in a high power factor value. This is because *power* is proportional to the *voltage*.

3.2. Power Factor Correction (PFC) by Using Two Converter

Based on the result as Table 3, it can be concluded that the reading of THD percentage has become lower compared to the reading using the Rectifier method. Even though the Bridgeless Topology can minimise the percentage of the THD, yet if this method is adopted on the load that contains a high reactance value (non-linear load), there is a possibility for the power factor to become poor. This is due to the fact that the value of reactive power is very high. Thus, by analyzing the power factor formula, it suggests that the reactive power (Q) is inversely proportional with the power factor. Therefore, when the value of reactive power is high, the value of power factor will become poor.

3.3 Power Factor Correction (PFC) By Using Two Active Converters

For the final analysis as Table 4, the method for PFC by using two converters is introduced. In this method, the first converter is referring to the Bridgeless topology and the second converter is using an interleaved topology. This method is proposed as an alternative to overcome the disadvantage of the second design.. THD result will be below than 5% and at the same time it will maintain the power factor correction ratio.

Table 3. Summary of PFC by using Bridgeless Topology

V_{in} (V)	load (resistor) ohm	load inductor (mH)	pfc	THD (%)
5	10	47	0.89	10.699
	10	100	0.892	10.699
	150	100	1	35.149
15	10	47	0.929	5.981
	10	100	0.928	5.981
	150	100	0.998	32.016
20	10	47	0.89	5.148
	10	100	0.935	5.148
	150	100	0.034	53.75

Table 4. Summary of PFC by using Bridgeless and Boost Converter

V_{in} (V)	load (resistor) ohm	load inductor (mH)	pfc	THD (%)
5	10	47	0.794	33.378
	10	100	0.717	30.466
	150	100	0.97	84.475
15	10	47	0.864	14.121
	10	100	0.808	13
	150	100	0.99	34.177
20	10	47	0.879	10.671
	10	100	0.838	9.293
	150	100	0.99	26.017

Table 5 is the summary of Power Factor correction method using Bridgeless topology and interleaved converter method. The interleaved converter method solves the issues of Bridgeless topology by using two Boost converters that are connected in parallel. The function of interleaved converter is to reduce the ripple in the input signal. Thus, if the ripple is reduced the distortion will also be reduced.

Table 5. Summary of PFC by using Bridgeless and Interleaved Converter

Vin (V)	load (resistor) ohm	load inductor (mH)	pfc	THD (%)
5	10	47	0.946	0
	10	100	0.946	9.77
	150	100	0.996	25.64
15	10	47	0.873	0
	10	100	0.851	2.28
	150	100	0.998	6.456
20	10	47	0.9	0
	10	100	0.9	2.17
	150	100	0.998	4.628

From the simulation findings, it can be concluded that this method reduces the reading of THD in comparison to the previous methods. Besides that, the power factor can be maintained at the value of 0.9. In compliance to this, among the discussed methods to amend the power factor for non-linear load, the most effective method is the combination circuit of bridgeless and double boost converter (interleaved converter). This is because the boost converter will increase the value of voltage output. Analysing Ohm's Law where the *power* is proportional to the *voltage*, so a high voltage will result to a high power (real power). Hence, it is possible to stabilize the reactive power value by using the method above. Nevertheless, these two methods can produce a prodigious result in Total Harmonic Distortion (THD) percentage and power factor value but there is still a need to control the load and the voltage input. This is because at certain loads and voltage level, there is a possibility for the value to fluctuate to its poor percentage of THD and power factor. The summary of the overall methods that have been opted to improve both parameters is concluded in Table 6.

Table 6. Summary of Results of the Proposed Methods

Methods	Passive Components of Rectifier Converter	Bridgeless Topology	Bridgeless Topology + Boost Converter	Bridgeless Topology + Interleaved Converter
Percent of THD	- Larger value	- Smaller value	- Smaller value and nearer to 0 percent. (5%)	- Smaller value, less than 5%
Power factor	- Close to unity power factor if the loads are high. - Poor power factor for lower loads.	- Close to unity power factor - Higher voltage gives better power factor.	- Close to unity power factor - Need to control the voltage input. - The power factor value depends on the voltage value.	- Close to unity power factor - The value of power factor depends on the loads.

4 CONCLUSION

In this paper, the relationship between the total harmonics distortion (THD) and Power Correction Methods (PFC) has been presented and it is dependent upon voltage input and loads. Thus,to ensure the power factor to be corrected well, all the parameters from the power source till the load must be considered in designing the PFC circuit. If the load contains more reactive power than the real power, the value of the voltage input needs to be increased and vice versa. This is because the value of power factor correction is proportional to the voltage input. Nevertheless, the percent of THD is inversely proportional with the voltage. The most effective method to amend the power factor for nonlinear load has been discussed in this paper.

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Rasidah Abdul Rani received her bachelor degree in electrical engineering (Industrial Power) from UTeM in 2007. After that, she received an Advance Diploma in Education in Engineering Technology from Univeriti Tun Hussien Onn in 2009. Then in 2015 she obtained her Master's Degree in Electronic Engineering (Electronic System) in UTeM. Furthermore, she holds professional membership of the Malaysia Highway Authority and has attended various additional courses in relation to the field. She has actively published many papers for conferences, seminars, and colloquium of mostly for Politeknik Sultan Azlan Shah. She is now a lecturer in Department of Electrical Engineering of Politeknik Ungku Omar.

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