Power Factor and THD Improvement Using PSIM Software

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Abstract— **Non-linear loads produce harmonic current and give bad impact to the power factor in electrical system. This paper investigates the methods that can improve power factor in system. There are two methods discussed namely passive filter PFC and active filter PFC. The main focus is on the active filter by using buck converter to improve power factor. There are two types of current mode control which are peak current mode control (PCMC) and average current mode control (ACMC). The ACMC method is used with buck converter improve power factor in electrical system. The simulation process is done b using PSIM software.**

Keywords; Active filter, Passive filter, Average current mode control (ACMC), buck converter.

I. INTRODUCTION

Nowadays, a lot of modern electrical equipments are non-linear in nature. Mostly the equipments convert AC to DC power conversion for operation. The non-linear load cause distortion on current input waveform has drawn from the source and it causes harmonics in electrical system. The shape of input current is not in phase with input voltage that gives significant effect to power factor in system. The single item such as computer does not affect the power factor. However, when a lot of computers are used at a same time in one building it gives major impact on power factor. If the low power is not corrected, the utility must provide the nonworking reactive power in higher energy consumption [1]. Based on the rules regulated by Tenaga Nasional Berhad, power factor surcharge is imposed to the user that have power factor less than 0.9 for 132kV and above of supply voltage and 0.85 for 132kV and below [2]. The improvements on power factor and the problem of harmonic can be solved by adjust the input side of the diode rectifier filter capacitor circuit [3]. The improvement of power factor can reduce the electrical bill, raise the voltage and reduce the losses of system.

Power factor measures how effective the current is being converted into useful work output [4]. Power factor is defined as the ratio between real powers to the apparent power [5]. The apparent power is formed by product of voltage and current. The unity power factor occurs when the current are sinusoidal and in a same phase. If the current lag or lead the voltage, the power factor becomes low due to harmonics produce by non-linear loads. . Besides, the current harmonics can deteriorate the power quality at the source. The harmonic problem can be solved by improving the power factor in system. Figure 1 shows the power triangle that relates the real power and apparent power.

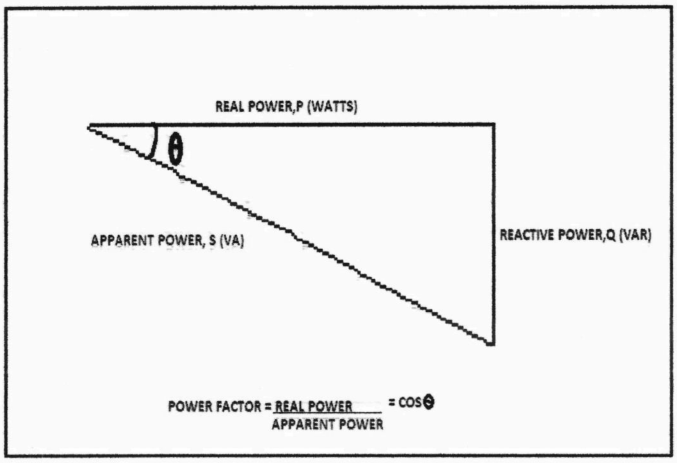


Figure 1. The triangle shows relation between real, reactive and apparent power.

II. POWER FACTOR CORRECTION STRATEGIES.

The switch mode power supplies is the main component cause low power factor and high circulating current in system. The solution to improve the power factor in system is by increasing the conduction angle of rectifiers [3]. There are two methods which are passive and active power factor correction. The passive solution is used for low power application. The passive elements such as inductor and capacitor are usually connected at the input circuit. The power factor at passive power factor correction can increase until 0.8 and distortion on input current will be lower. Using passive elements as power corrector the ability to achieve to unity is impossible and it makes the passive elements is suitable for low power level. Active power factor correction is most suitable for achieving high value power factor. It can achieve the value of power factor near to unity and in the meantime the distortion of line current can be reduced. In this filter, a converter with high switching frequencies than AC line frequency is placed between the capacitor and output of diode bridge rectifier. The purpose of this converter is to make the load is similar as ideal resistive load and at the same time it can eradicate the current harmonic.

The types of single-phase off-line PFC topologies are shown in Figure 2. Based on the PFC topologies, a certain topologies are considered which are the passive and high frequency active types.

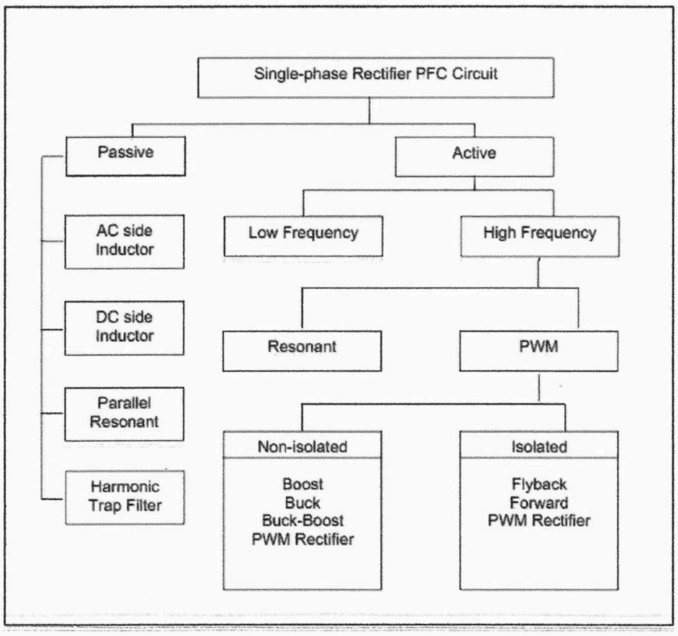


Figure 2 Types of Single-Phase off-line PFC topologies. [7]

III. PASSIVE POWER FACTOR CORRECTION

The basic AC-DC converter consists a full bridge rectifier and followed by filter capacitor at output side. A passive PFC uses passive elements such as inductor and capacitor to improve the power factor in the system. Usually, the inductor is put on the AC side or input side to act as filter. The input current of a rectifier consist of large discontinuous peak current and it will produce current of harmonic at input side. The value of inductor need sufficiently large for store enough energy to maintain the rectifiers in conduction for the half cycle. The passive PFC circuit only can carry until 400W. If the rating power is greater than 400W the active PFC circuit is necessary. However, the series inductor has disadvantages due the losses occur due to resistance of inductor, the load voltage become lower due to voltage drop and the resonance that produce from filter capacitor. Generally, the passive PFC improves the power factor in electrical system and reduces the harmonic currents but it does not eradicate the problem completely [3]. Figure 3a and 3b show the block diagram of passive filter and the waveform of input voltage and current respectively.

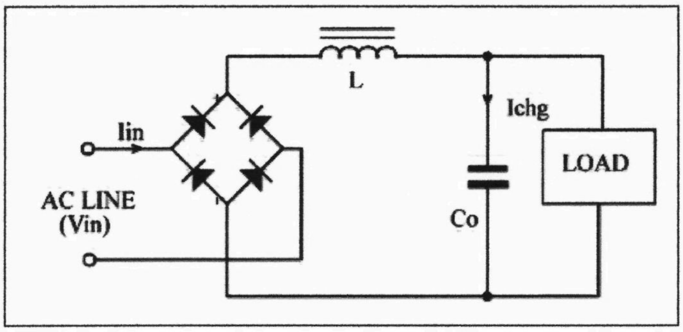


Figure 3a. Block diagram of passive PFC circuit

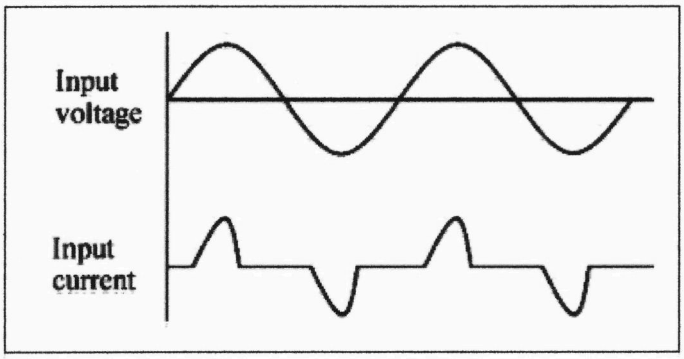


Figure 3b. Input voltage and current in passive PFC

IV. ACTIVE POWER FACTOR CORRECTION

The active PFC are usually used in electrical system for large power consumption. It can improve power factor efficiently compared to the passive PFC. It can improve power factor until 95% in the system. There are two types of active PFC which are low frequency active PFC and high frequency active PFC. In the meantime, active PFC can clearly diminish the harmonic current and automatically correct the input and current voltage. The active filter mostly more complex and more expansive compared with the passive filter [3].

In this paper, the high frequency active PFC is used to improve the power factor. The high frequency active PFC consists of buck or boost converter or buck-boost converter and placed it in between bridge rectifier and the filter capacitor. The function of converters is to control the shape of input current. Generally, for all the converter topologies, the switching frequency is higher than the line frequency and the output DC is regulated. The PFC output voltage can be either higher or lower and it depends on the types of converter used. The buck converter will give low output voltage and the boost converter will give higher output voltage. While the buck-boost converter, the output voltage can be either higher or lower.

The inductor current for all converters can be either discontinuous or continuous. In the discontinuous mode, the current falls to zero at the switching cycle. While in the continuous mode, the current never falls to zero. The high switching current components of the AC input current can perform continuous only using boost converter. This is because the other converter switch interrupts the input current during every switching cycle. The inputs current waveforms depend on the types of converter used. The inductors current are assumed in continuous mode operation. In this paper, the buck converter is used based on the active PFC.

V. BUCK CONVERTER BASED ON THE ACTIVE PFC

The output voltage of buck converter is less than the input voltage [6]. It is same as step-down converter. The basic buck converter circuit is shown in Figure 4.

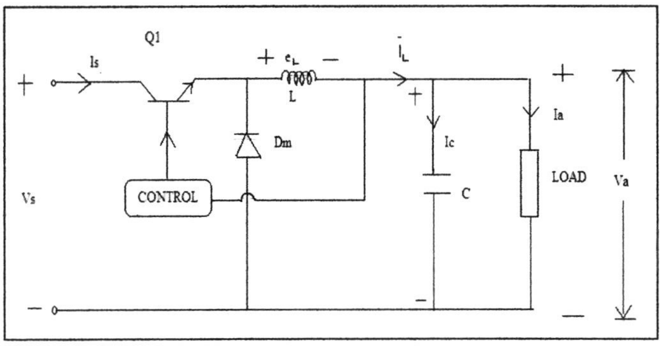


Figure 4. Buck converter circuit diagram [8]

The converter only can operate when the instantaneous input voltage is higher than the output voltage. The line current will be distorted near the input voltage zero crossing. Even though the inductor current is continuous but the input switching current of the converter is discontinuous. It is because the high frequency switching interrupts the input current for every switching cycle. Therefore the input current has high-frequency components and it will increase the EMI and filtering necessities [3].

IV. CURRENT MODE CONTROL

The buck regulator input current is programmed to be proportional to the input voltage waveform and it will correct the power factor in the system. Current mode control consist two-loop system to control input voltage for power factor correction and the feedback is necessary to control the input current at AC side. The outer loop is the voltage control loop and it can improve the power supply performance. There are two types of current mode control which are peak current mode control (PCMC) and average current mode control (ACMC). In this paper, the ACMC will be discussed.

The ACMC is a simple concept where the amplifier is used in the feedback loop around the buck power stage. From the feedback operation the input current follows the current programming signal. The power circuit of buck converter consists of a single phase rectifier to rectify the AC input voltage. At the output side, the input current is programmed by the input voltage to improve the power factor.

The input of the converter will be resistive when the current loop is programmed by rectified line voltage. The average amplitude of the current programming signal is to control the output voltage. The average multiplier is used to rectify the line voltage with the output of the voltage error amplifier to give the current programming signal (Imo) which has the shape of the input voltage and average amplitude to control the output voltage. The multiplier input from the rectified line voltage shown as a current signal. The voltage loop consist the squarer, divider and multiplier. The output of the voltage error amplifier (Vvea) is divided by the square of the average input voltage before being multiplied by the input voltage signal. This is the way to keep the gain of the voltage loop in constant. The voltage loop bandwidth is less than the input line frequency. It is because if the voltage loops bandwidth greater than input line frequency it will moderate the input current and the output voltage will be constant and will result in large distortion in input current. At the same time the value of voltage loop bandwidth should be large enough to get the fast output voltage transient response. The divider and square block is used to keep the loop gain constant and it will result the loop bandwidth is close to the line frequency and it can minimize the transient response of the output voltage. This circuit is keep the loop gain constant and make the voltage (Vvea) a power control which control the power delivered to the load [9]. The basic control circuit for active power factor corrector is shown in Figure 5.

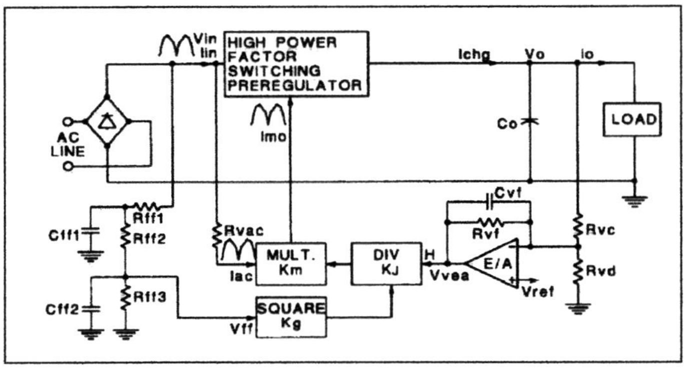


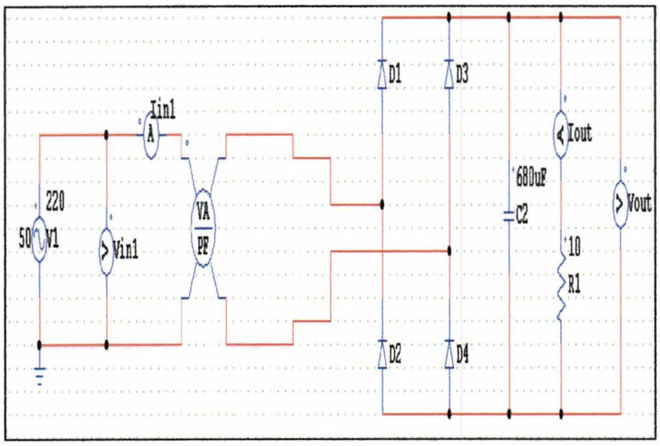
Figure 5. Active power factor corrector circuit.

The displacement and the distortion of input current waveform is introduced by control circuit. The input bridge, ripple and the multiplier is the source of error. There are two processes that involved in active power factor corrector which are the input diode bridge and the multiplier, divider and the squarer circuit. The harmonics is generated between the two inputs during the modulation process. The two modulations are interacting and one of it serves as a demodulator. The Vff value should be as low as possible to minimize the distortion in input current. By using ACMC the line regulation will be better. Other than that, the ACMC operates with a constant switching frequency.

VII. SIMULATION RESULTS AND DISCUSSION.

a) Diode bridge rectifier without using PFC.

A diode bridge rectifier has been set up and the value of power factor is 0.69. The value of power factor is very low because at the load the voltage drop is very high and at the input side the line current is distorted with large harmonic currents. The percentage of harmonics in this circuit is 65.6%. Figure 6 shows the circuit diagram and input of line voltage, line current power factor and frequency spectrum without using PFC.



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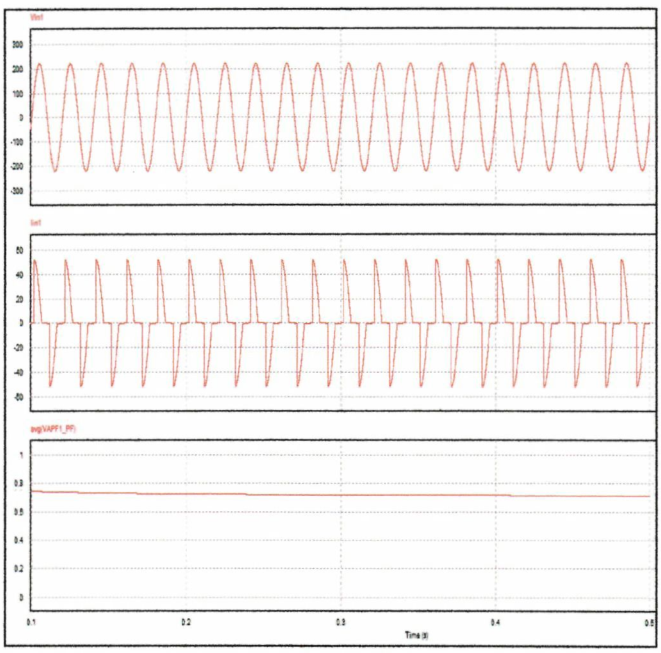

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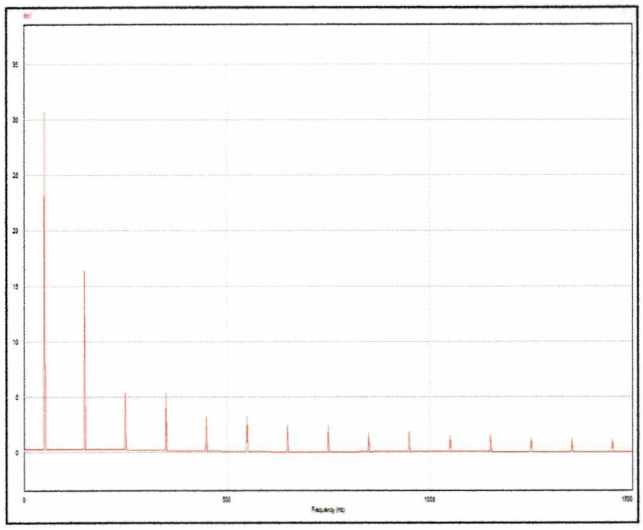

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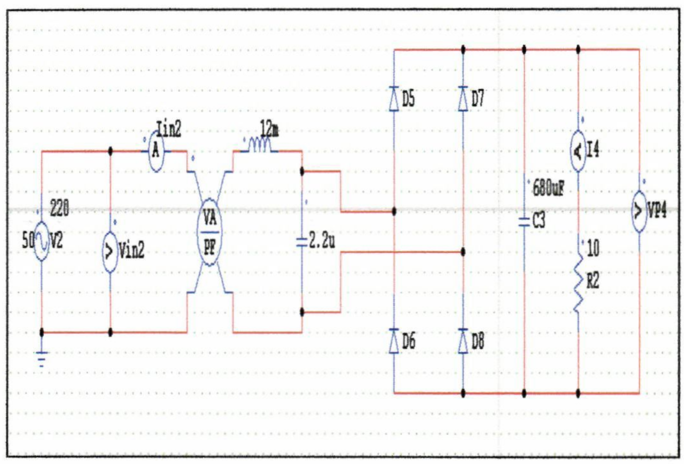
Figure 6. Single phase diode bridge rectifier. a) Simulation circuit. b) Line voltage, line current and value of power factor. c) frequency spectrum.

b) Passive filter as PFC.

A simple method of passive power factor is to add an inductor and capacitor between the AC side and the diode bridge rectifier. The function of the inductor and capacitor is to filter out the distorted current for the rectification action. If the value of inductor is large, the current will be in continuous mode and never reaches to zero. In meantime, the distorted input current will diminish. The maximum power factor when used this method is 0.79 and the percentage of harmonics is reduce to 27% Figure 7 shows the circuit diagram and the input line voltage, line current, power factor and frequency spectrum by using passive filter.



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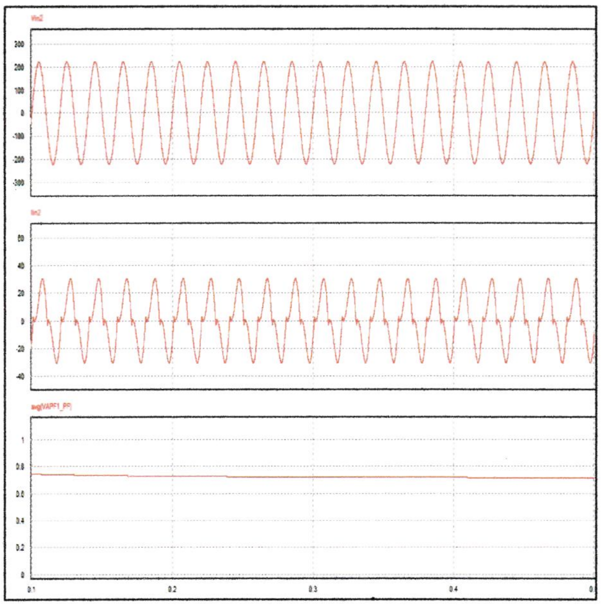

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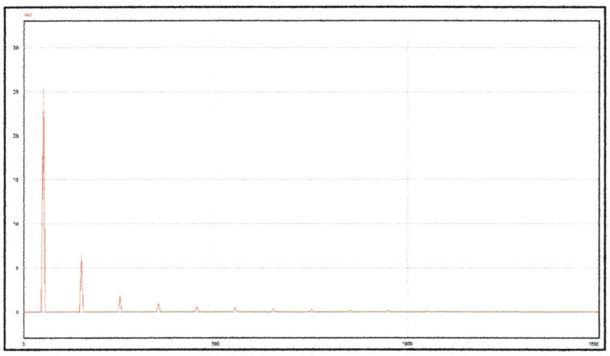

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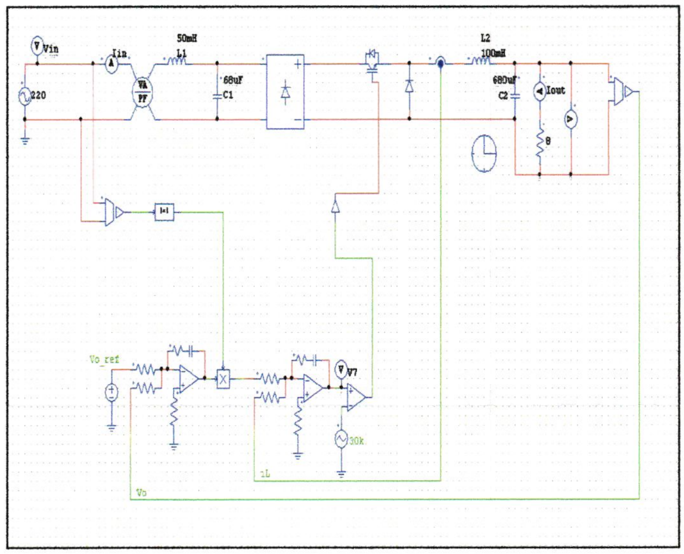
Figure 7. Rectifier with AC side inductor. a) Schematic diagram. b) Line voltage, line current and value of power factor. c) Frequency spectrum.

c) PFC using Average Current Mode Control (ACMC)

The PFC with ACMC as power factor correction is a simple concepts where the amplifier is used in the feedback loop around the buck power stage. In resulting, the input current follows the current programming signal with minimum error. There is a single phase diode rectifier to rectify the AC input voltage. The output from the buck regulator is constant voltage but the input current is programmed by the input voltage. The method are involves the control of both input current and the output voltage by using the control circuit. The power factor is increase to 0.94 because the displacement between input current and input voltage is small. Using this method also reduced the distortion input current and the percentage of harmonic reduces to 5.89%. Figure 8 shows the simulation circuit and the input line voltage, line current, power factor and frequency spectrum.



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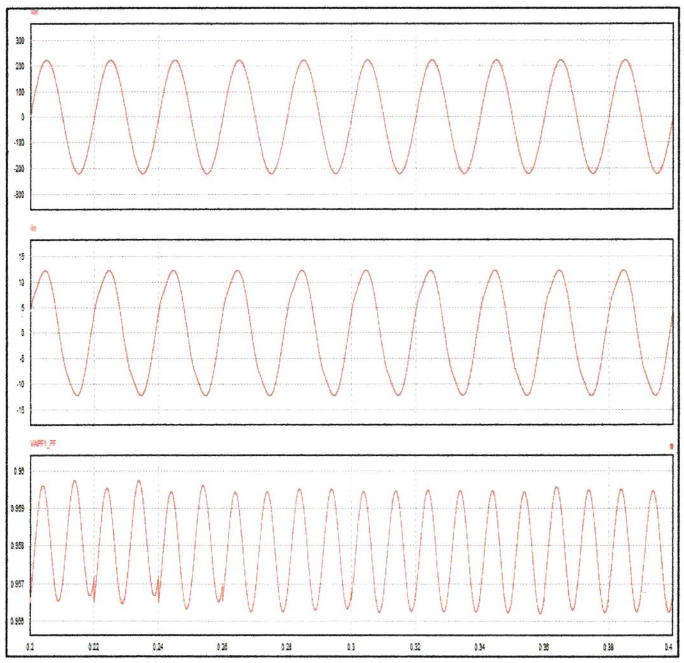

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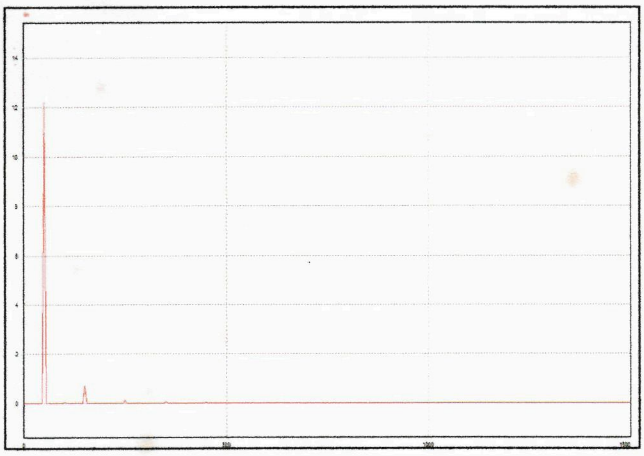

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Figure 8. PFC using ACMC. a) Circuit diagram. b) line voltage, line current and value of power factor. c) Frequency spectrum

Table 1. Result of power factor and percentage of harmonic with different methods.

Method	Value of Power Factor	Percentage of harmonic (%)
No filter added	0.69	65.6
Passive filter	0.79	27
Active Filter	0.94	5.89

VIII. CONCLUSIONS

In this project, it can be concluded the conventional AC rectification is very inefficient process because the current drawn from the power line will distorts the current waveform. It is also produces the harmonic in the system that will affect the other equipments in system.

In conclusion, the power factor can be improved when using the passive and active filter. It also can reduce the bad harmonic in the system. The passive power factor correction circuits have certain advantages, such as reliability, simple design, insensitivity to noise, no generation of EMI and no high frequency switching losses. Active power factor correction circuit using ACMC with buck converter is more suitable options for power factor correction because it can achieve the power factor near to unity. Active PFC also reduces the distortion at the input current and phase displacement between input voltage and current. In this method, a converter with high frequency switching than line frequency is placed between the bridge rectifier and capacitor. The reactive elements of the converter are small because their size is depends on the switching frequency.

IX. ACKNOWLEDGMENT

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