Single Phase Rectifier with Power Factor Correction Implementation

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***Abstract* – Single phase rectifier with power factor correction (PFC) was developed using boost topology. Single phase rectifier is a converter to convert AC to DC waveform. The main function of this technique is to correct the pulsating of input current to nearly unity power factor with low total harmonic distortion (THD). This technique used current control loop (CCL) to control the pulse. The low power factor and high THD of the rectifier was due to non-linear input current. The result from the single phase rectifier with PFC implementation was compared without PFC control. The IEEE519std on harmonic was used as the reference to determine the performance of the developed rectifier.**

***Keywords* – Single phase rectifier, power factor correction, total harmonic distortion (THD), current control loop (CCL).**

I. INTRODUCTION

Nowadays rectifier is a very important for power switching circuit in industrial application. Rectifier is a converter to convert AC to DC either in term of current waveform or voltage waveform. The rectifier will use diode and thyristor for uncontrolled and controlled rectifier with unidirectional and bidirectional power flow. Rectifier will contribute low power factor (PF), high total harmonic distortion (THD) and low efficiency to the power system. Most of electrical devices have harmonic such as personal computer, radios, fax machine and any other equipment powered by switched mode power supply equipment. A typical single phase rectifier and input current are shown in Fig 1[1] and Fig 2 [1]. Power factor (PF) is defined as the ratio of real power and apparent power. Equation (1) shows the relationship between real power and apparent power. It measure the effectively of the current being converted into useful work output. When electric load has a PF lower than 1, the apparent power delivered to the load is greater [2]. The power factor mostly depends on the input source impedance and the characteristic of the load.

$$PF = \frac{Real\ Power(KWatt)}{Apparent\ Power(KVA)} \quad (1)$$

PFC rectifiers are one of the cheapest methods to maintain the input sinusoidal current waveform. There are two types of PFC, passive PFC and the other one is active PFC. Passive PFC only use diode, capacitor, inductance and other passive component. The value of power factor for passive PFC can reach about 0.7 to 0.8. Passive PFC requires a large value of inductor current and, it so expensive and bulky. Active PFC need power switching and IC controlling, the cost of active PFC higher then passive PFC. PFC rectifier using boost topology is a most popular to improves power factor and reduce current harmonic. There are several methods for PFC rectifier such as average current control, hysteresis control, nonlinear career control and indirect current control [3]. Discontinuous input current that exists on the AC mains caused by the non-linearity of the rectification process could be shaped to follow the sinusoidal form of the input voltage. The process of shaping the input current is done by the Boost converter [4]. Boost converter is the most suitable for power factor correction application among buck and buck-boost topology. The inductor is in series with the input and diode rectifier, which gives lower current ripple.

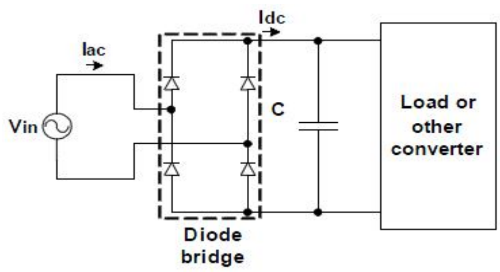

Fig 1: Single phase diode rectifier [1]

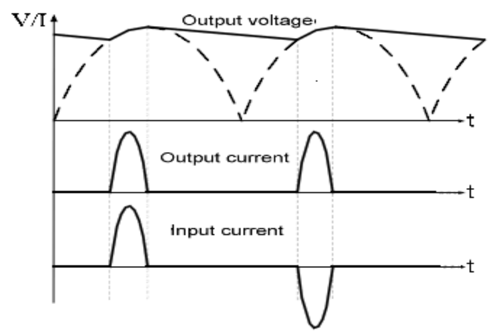

Fig 2: Input and output current [1]

II. BOOST TOPOLOGY

Generally, boost converter is a power converter with the value of output DC voltage higher than input DC voltage: i.e. $V_{OUT} > V_{IN}$. A boost converter is sometimes called a step-up converter. Most of electric power supply use boost converter to increase the voltage. Filter like capacitor or combined with inductor are normally added to the output of converter to reduce output voltage ripple. The operation of boost circuit such Fig 3 can be dividing on two modes, for the mode one, the switch will turn 'ON' and inductor will store energy. For mode two, when the switch turn 'OFF' inductor will release the energy and a capacitor will store the energy. Figure 4 shows the charging operation of capacitor and inductor.

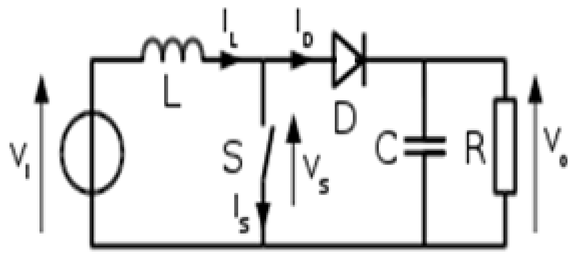

Fig 3: Basic Diagram of Boost Converter

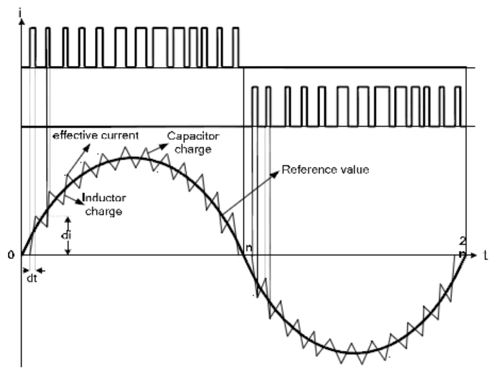

Fig 4: Inductor and Capacitor Charging

Boost circuit is a simplest topology to design PFC rectifier because its only use a single switching to controlled. However, the uncontrolled bridge circuit may not be used in bidirectional and regenerative operations [5]. Fig 5 shows the ideal waveform for switching, input current through inductor, current through switch and current waveform through the diode. Figure 6 shows the concept of PFC rectifier where the main AC input voltage is rectified and supplied to the Boost converter. The current sensor will capture the current waveform in term in voltage to provide the input current waveform. The Boost converter, that mainly consists of inductor, a power switching, a power diode and a load. A power switching like IGBTs or MOSFET needs a driver to amplifier the current and turn ON the power switching.

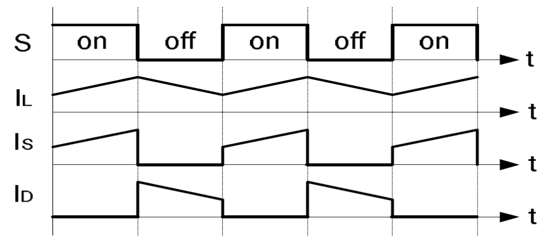

Fig 5: Ideal Waveform of Boost Circuit [7]

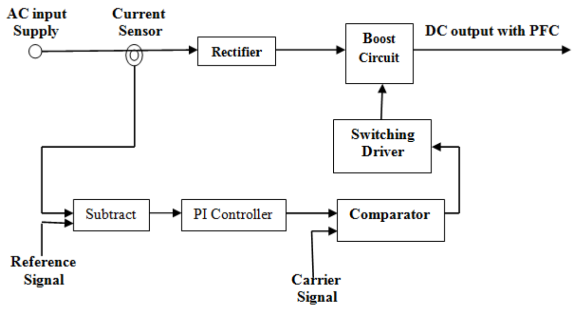

Fig 6: PFC Rectifier Concept

III. SIMULATION

The simulations of this single phase rectifier with PFC implementation are using Matlab/Simulink with SimPowerSystem. The experimental has been done to verify the performance operation and to compare the result with simulation using Matlab. Fig 7 shows the main model of the PFC rectifier using Matlab/Simulink. The subsystem will be used to minimize large model of the circuit. From this circuit it can be divided into five part of subsystem. The part of subsystem in the project is source, full bridge, boost circuit, current controller and scope to display the result. The source that used in this project is a 40AC voltage and inductor will provide at the input side as a filter. The value of inductor in this project is 1mH. Fig 8 shows the connection of AC source and inductor. Fig 9 shows the circuit of the full bridge where the AC voltage or current will convert to DC output. Boost circuit will be used insulated gate bipolar transistor or IGBTs for the power switching devices. The load was a combination DC capacitor and resistor. The function of the load was to remove the ripples for this system. Fig 10 shows the boost circuit using Matlab/Simulink. The value of resistor in this circuit is 100Ω and the value of capacitor is 1mF. The switching frequency that was used in this project is 10 kHz. The function of the diode in this circuit is to block the current flow reverse bias. From Fig 11, the current control loop (CCL) is to provide control to the system by monitoring the supply current waveform and making corrections by current compensation technique [1]. Current input from the current sensor will be subtracted from the reference signal or sine wave and it will get the error signal. The error signal will through the pi controller to reduce the value of error. The value of Kp and Ki will be set as a Table 1. The output signal from the pi controller will be compare with the triangle signal to get the pattern of switching.

The PWM (Pulse Width Modulation) technique is used to synthesize the injected current as shown in Figure 12. The output of current controller will provide the switching signal to the IGBTs. It also provides the switching function to compensate the distorted current into sinusoidal signal.

Table 1: Parameter of Controlled Rectifier with PFC

Boost inductor	1mH
Switching Frequency	10kHz
Proportional Gain, Kp	8
Integral Gain, Ki	27

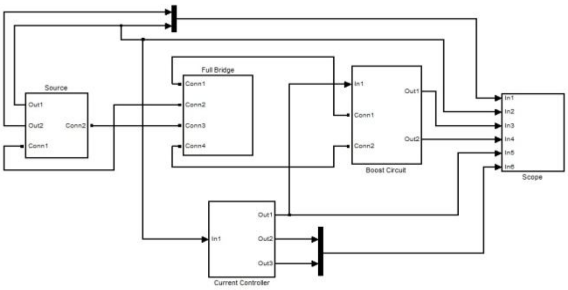

Fig 7: PFC Circuit

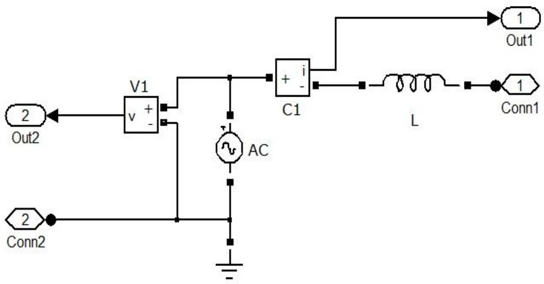

Fig 8: Voltage Source

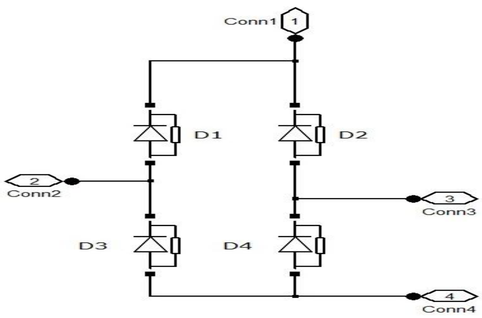

Fig 9: Full Bridge

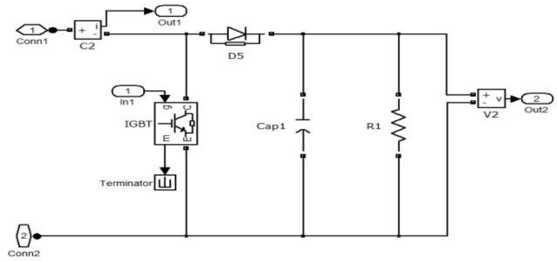

Fig 10: Boost Circuit

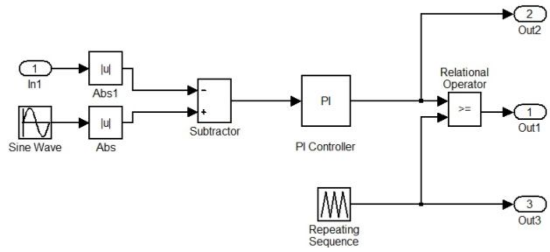

Fig 11: Current Controller

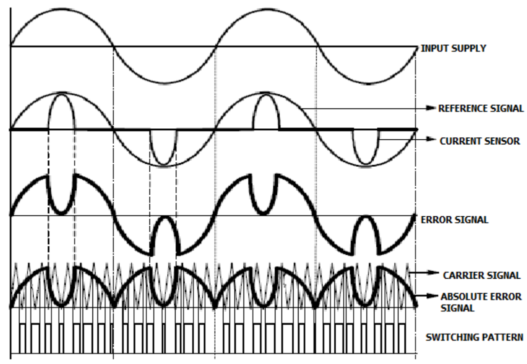

Fig 12: Switching Pattern of PFC Rectifier

IV. RESULT AND DISCUSSION

Fig 13 and 14 shows the distorted current input and voltage source waveform of non-linear load without any filter solution. Fig 15 shows the voltage output waveform without implementation of PFC. Fig 16 and 17 show the current input and voltage source waveform with the implementation with PFC. The current input become sinusoidal after implement with PFC. Fig 18 shows the output voltage after implementation. The performance of PFC rectifier can be seen in Table 2 where the value of THD and power factor before implementation is 127.66% and 0.663. After implementation of PFC the THD and power factor value become 3.03% and 0.985. Figure 19 and 20 shows the current and voltage input without and witht PFC implementation by experimental. Figure 21 shows comparison of the THD spectrum obtained from simulation using Matlab/Simulink with the IEEE519 Standard.

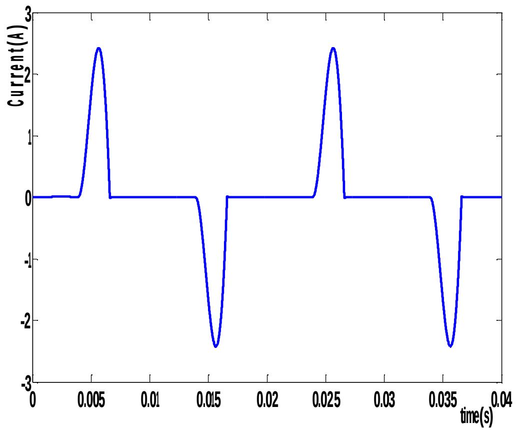

Fig 13: Current Input without PFC

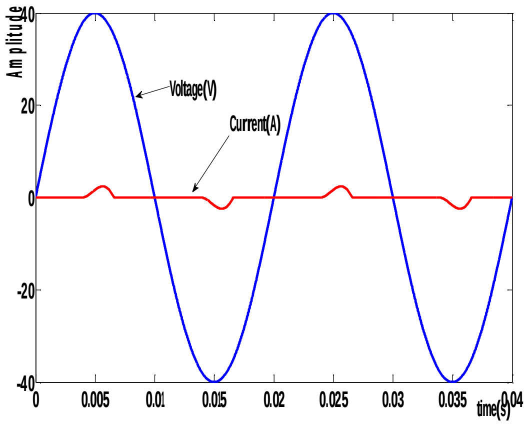

Fig 14: Current and Voltage Input without PFC

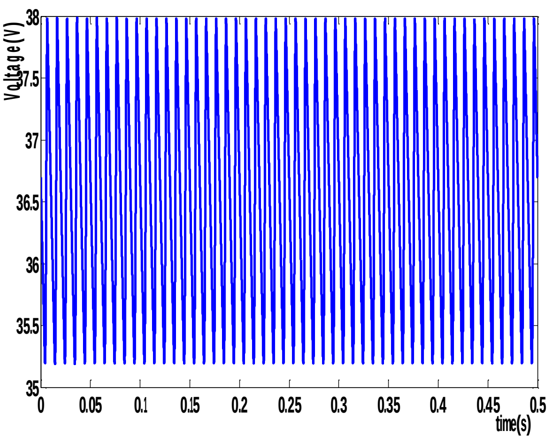

Fig 15: Output Voltage without PFC

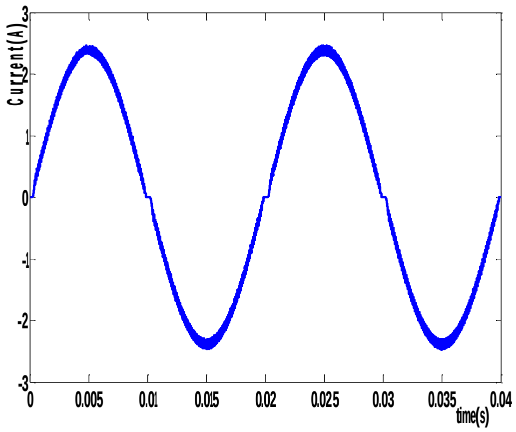

Fig 16: Current Input with PFC

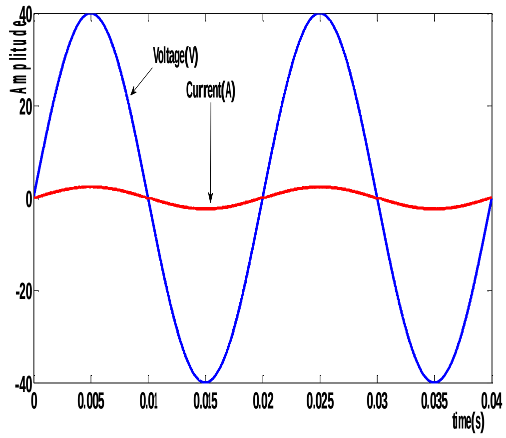

Fig 17: Current and Voltage Input with PFC

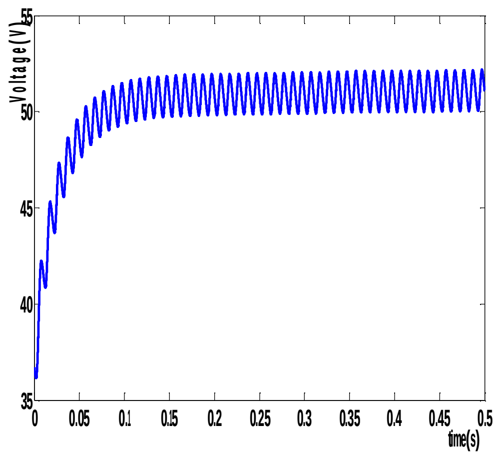

Fig 18: Output Voltage with PFC

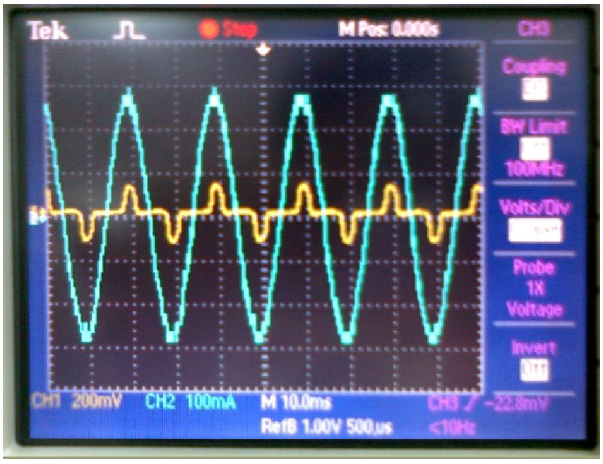

Fig19: Experimental- Current and Voltage Input without PFC

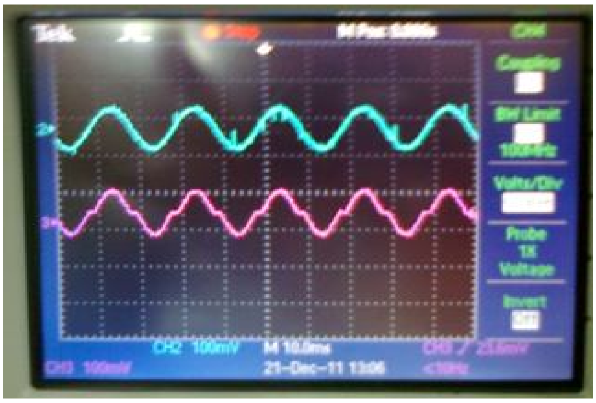

Fig20: Experimental – Current and Voltage Input with PFC

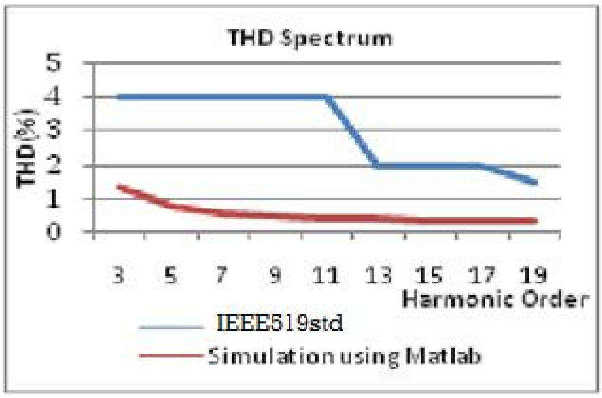

Fig 21: THD spectrum of supply current with PFC

Table 2: Comparison THD and Power Factor

	SIMULATION(THD)	POWER FACTOR
Without PFC	127.66%	0.663
With PFC	3.03%	0.985

V. CONCLUSION

This paper presents the details operation of controlled rectifier with PFC using Boost Converter. IGBTs where used as the main power switching device. PFC rectifier has been modelled and simulated using Matlab/Simulink. From the result, it is shown that the Boost Converter is a very versatile topology for the future development to increase the power factor. The distorted input current contains harmonic components with a THD 127.66%. Using current control loop, the THD for input current has been reduced to 3.03% and giving almost pure sinusoidal waveform. The input current is now in phase with the voltage input.

VI. REFERENCES

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