ACTIVE FILTER PERFORMANCE IMPROVEMENT ON SINGLE-PHASE RECTIFIER CONTROLLED BY USING PULSE WIDTH MODULATION (PWM)

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ABSTRACT

Using active filters is one *solution to improve the power factor and reduce harmonics in the input voltage. The use of active filters can improve the performance of passive filters but still has some drawbacks, such as high harmonics. Therefore, various techniques, such as forced switching, ignition angle control, and symmetrical angle control, have been developed to increase the input power factor and harmonic level. However, all of these techniques will produce only one pulse per half cycle of the converter input current, and as a result, the lowest order harmonic is the third harmonic. This research aims to conduct a comparative study of active filter converters between single pulse and PWM control. Both converters are given identical R and RL loads to compare power factor (PF) and Total Harmonic Distortion (THD). The method used is a simulation with the PSPICE program. The performance of both rectifiers is evaluated based on the input current waveform, THD, and PF. At RL load, the input current distortion decreases drastically, with a THD of 106.4%. In the PWM control, there is a decrease in harmonics with a THD of 25.48%. The rectifier power factor on the active filter obtained a PF of 0.25, while in the PWM control, the PF increased by 0.65.*

Keywords: *active, passive, harmonic, ripples voltage*

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1. INTRODUCTION

In recent years, the harmonics in the power system have been severe due to the wide applications of the electronic equipment in which the AC/DC converter is usually used. Solid State Frequency Converters (SSFC) have traditionally used Silicon Controlled Rectifiers (SCR) or Thyristor to convert AC power to DC power. Applied phase control, average values of load voltage can be controlled and varied [1-4]. SCRs have the advantage of being easy to control and inexpensive. They have to be turned on or off at the zero-crossing point of the AC sine wave. The output voltage of a controlled rectifier depends on the firing angle. In addition, an SCR-controlled rectifier works as an uncontrolled diode rectifier when the firing angle, α, of the thyristor is zero. However, it has several significant disadvantages. In [5, 6], a controlled rectifier produces high harmonic distortions in the input current waveform and a deficient power factor. They lower the input power factor by taking more reactive current and inducing commutation spikes into the utility power supply. Therefore, high harmonic levels in the system are not desired because they can cause many losses, such as increased distortion of inputs, failure of sensitive electronic equipment, and lower efficiency. The negative impacts of non-linear loads on the quality of the electrical energy supply are called system perturbations or electrical pollution.

Many efforts have been performed to reduce harmonic contents in the input voltage of the controlled rectifier. Many researchers have used passive filters with different configurations [7-10], but this technique suffers from bulky, heavy filter elements and sometimes causes resonance problems. Alternatively, people have developed active filters as an attractive option, but these techniques are complex and expensive [11, 12]. In addition, the active filter uses only one single pulse per half cycle [13, 14]. Consequently, it produces a third harmonic in practice, and it is complicated to do low harmonic filtering. In [15, 16] proposed a hybrid type using active filters and passive filters to improve passive filter performance. However, this scheme suffers from bulky construction and resonant problems, and the current in the injection branch is very sensitive to the deviation of the *L* and *C* values.

Several previous studies with Pulse Width Modulation (PWM) controls have developed a new technique. This method allows the creation of several pulses per half cycle that can reduce harmonics. The PWM control method was first developed and applied to the transistor converter to reduce peak current by [17]. To date, several efforts have been made to improve the input current distortions, concentrating on PWM control schemes. In [18, 19] conducted the concerns a variable switching frequency PWM. In PWM control, the switch on the rectifier works when the current on the dc side of the rectifier drops to zero. In this condition, the switch is immediately turned on again. However, this control scheme suffers from a severe defect; the switching frequency is load-dependent. A lighter load and increased switching frequency result in high switching losses, and the wide switching frequency range complicates boost inductor design, device selection, and EMI filter design.

In connection with the performance of PWM rectifiers, several simulation models are performed by the researchers. A detailed analysis for determining the relation between the injection current's optimal amplitude and phase angle, along with the firing angle, has been carried out with PSIM simulation [20]. Using MATLAB software, Venkatesh presents the modeling and simulation of 6-pulse and 12-pulse rectifier topologies to compare their input current harmonics, output voltage ripples, and Total Harmonic Distortion (THD) as well [21]. In [22], a comparison of performance for three pulses and 12 pulses PWM rectifiers are made. They are also using Matlab/Simulation model. Meanwhile, A. Zammouri et al. [23] have developed a PWM rectifier circuit analysis with Arduino and FPGA-based NI Lab VIEW.

In this paper, we use the PSPICE Program (release 7.1) [24] to analyze the performance of a single-phase controlled rectifier with an active filter compared to PWM control. The researchers and the ideas presented in this study demonstrated this technique's superiority in reducing the line current's harmonic content and increasing the power factor of a single-phase controlled rectifier. The system investigated in this paper is a single-phase, full-wave controlled bridge rectifier. Circuit diagrams, mathematical expressions, and voltage and current waveforms are presented for each rectifier given a resistive (R) and inductively resistive (R, L) load.

2. METHODS AND MATERIALS

2.1 Research Procedure

In this study, a descriptive method was used through PSPICE simulation. It aims to get an overview of the performance comparison of single-phase controlled rectifiers with active filters between PWM and non-PWM controls. The stages are shown in Figure1.

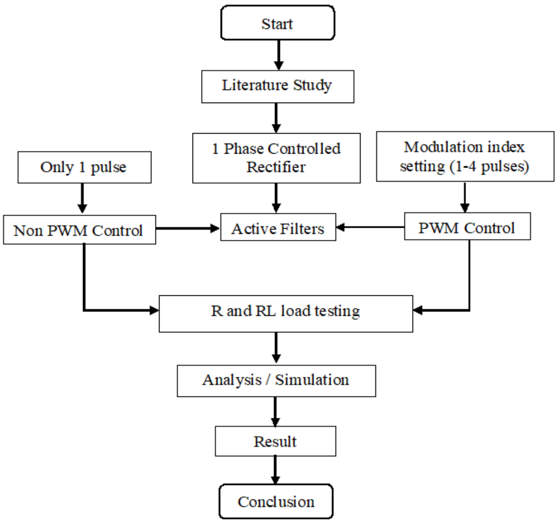
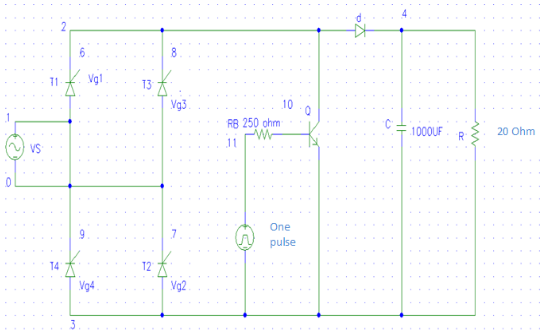


Figure 1. Research block diagram

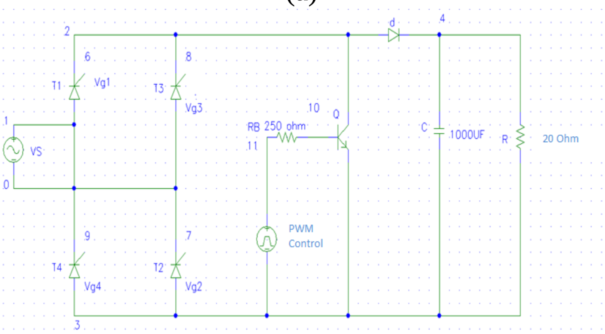
2.2 Modeling simulation and rectifier circuit specification

PSPICE software release 7.1 was used in this study. Fig.2 and 3 show the rectifier circuit simulated with different loads. The controlled rectifier is designed with the following specifications:

- AC single phase voltage source 220 V, 50 Hz.
- Full wave rectifier.
- Load value R = 20 Ohm, and L = 100 mH.

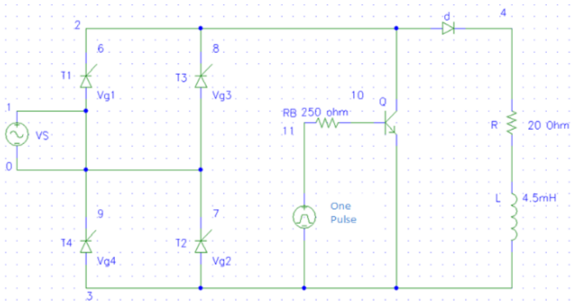


(a)

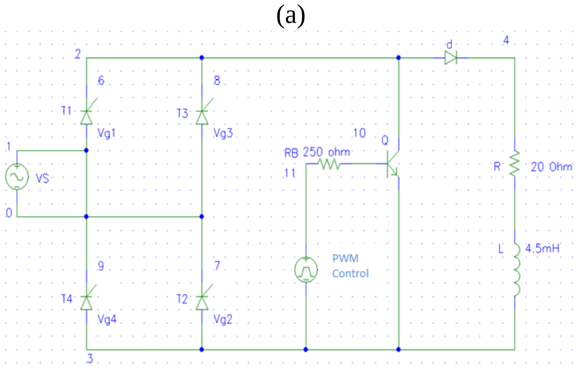


(b)

Figure 2. Single-phase controlled rectifier circuits with R load, (a) one pulse, (b) PWM control (4 pulse per half cycle)



(a)



(b)

Figure 3. Single-phase controlled rectifier circuits with RL load, (a) one pulse, (b) PWM control (4 pulse per half cycle)

2.3 Data Analysis

Following the purpose of this study, then we perform data analysis based on descriptive statistical studies in the form of percentage values and find the average value based on the simulation results. The equation determines the power factor:

$$PF = \sqrt{(1 - THD)^2}\, cos\emptyset \qquad (1)$$

The practical value (RMS) of the AC component output voltage, the following equation is used:

$$V_{ac} = \sqrt{{V_{rms}}^2 - {V_{dc}}^2} \qquad (2)$$

Then the ripple factor is determined by:

$$RF = \frac{V_{ac}}{V_{dc}} x100\% \qquad (3)$$

Output load power as follows:

$$P_{AC} = \frac{{P_{RMS}}^2}{R} \qquad (4)$$

and,

$$P_{DC} = \frac{{P_{DC}}^2}{R} \qquad (5)$$

From equation (4) and (5) obtained output power efficiency:

$$\eta = \frac{P_{DC}}{P_{AC}} x100\% \qquad (6)$$

3. RESULT AND DISCUSSION

3.1 Use of PSPICE and PWM Control

There are two ways to use PSPICE programming packages for simulators: the schematic sub-program and the program netlist written based on the definition of the circuit. This research used a netlist to simulate the performance of a single-phase controlled rectifier. The output of the simulation is a waveform and numerical data. The waveform observed is the output voltage waveform, input voltage, and load current. At the same time, the numerical data studied are the input and output voltage harmonics after controlled PWM, current harmonics, PF, and THD. Figure4 and 5 illustrate a PWM waveform input and output by comparing sinusoidal waves and triangles (4 pulses per half cycle).

The netlist of the PSPICE program has been compiled as follows:

```
* Schematics Netlist *
*Rectifier with PWM control
.PARAM VM1={SQRT (2)*220}
.PARAM PR={1/50},ALFA 30.0
.PARAM PLS1={(ALFA/360)*PR}
.PARAM PLS2={((ALFA+180.0)/360)*PR}
*Input Voltage:
VS 1  0 SIN (0 {VM1} 50HZ)
Vr 13 0 PULSE (0 10V 10000US 1250US 1250US 1NS
2500US)
Rg  7 0 2MEG
VC 10 0 SIN (0 10V 50HZ)
*VC 10 0 PWL (0 0 1NS 4V 50MS 4V)
*Firing of Thyristor:
Vg1 6 2 PULSE 0 10V {PLS1} 1ns 1ns 100us 20000us
Vg2 7 0 PULSE 0 10V {PLS1} 1ns 1ns 100us 20000us
Vg3 8 2 PULSE 0 10V {PLS2} 1ns 1ns 100us 20000us
Vg4 9 1 PULSE 0 10V {PLS2} 1ns 1ns 100us 20000us
*Schematic for R Load
RB 11 10 250
R   4 12 20
VX  5  3 DC 0V
VY 12  1 DC 0V
D   2  4 DMOD
Co  4  3 1000UF
*Schematic for RL Load
RB 11 10 250
R  4 12 20
L  12 25 100mH
VX  5  3 DC 0V
VY 12  1 DC 0V
D   2  4 DMOD
Co  4  3 1000UF
Q1  2 10 3 3 2N6546 ;BJT SWITCH
.MODEL 2N6546 NPN (IS=6.83E-15 BF=13 CJE=1PF
CJC=607.3PF TF=26.5NS)
.MODEL DMOD D(IS=2.2E-15 BV=1200V TT=0 CJO=0)
*Thyristor
XT1 1 2 6 2 SCR18CF
XT3 0 2 8 2 SCR18CF
XT2 3 0 7 0 SCR18CF
XT4 3 1 9 1 SCR18CF
*Modeling Thyristor
.SUBCKT SCR18CF 1 2 3 2
S1 1 5 6 2 SMOD
RSNUB 1 8 200
CSNUB 8 2 1UF
RG 3 4 50
VX 4 2 DC 0V
VY 5 7 DC 0V
DT 7 2 DMOD
RT 6 2 1
CT 6 2 10UF
F1 2 6 POLY (2) VX VY 0 50 11
.MODEL SMOD VSWITCH (RON=0.0105 ROFF=10E+5 VON=0.5
VOFF=0V)
.MODEL DMOD D(IS=2.2E-15 BV=1200V TT=0 CJO=0)
.ENDS
*Modeling PWM
.SUBCKT PWM     1       2        3        4
*      model  ref.  carrier  +control  -control
*      name  input   input    voltage   voltage
R1  1 5 1K
R2  2 5 1K
RIN 5 0 2MEG
RF  5 6 100K
RO  6 3 75
CO  3 4 10PF
E1  6 4 0 5 2E+5
.ENDS PWM
XPW 13 10 11 3 PWM
*Keluaran Simulasi
.TRAN 50US 160ms 20ms 50us
.PROBE
*Analisa Fourier
.FOUR 50HZ I(VY), V(4,3)
.PRINT TRAN I(VY)
.OPTIONS ABSTOL=1.00N RELTOL=0.01 VNTOL=0.01
ITL5=60000
.END
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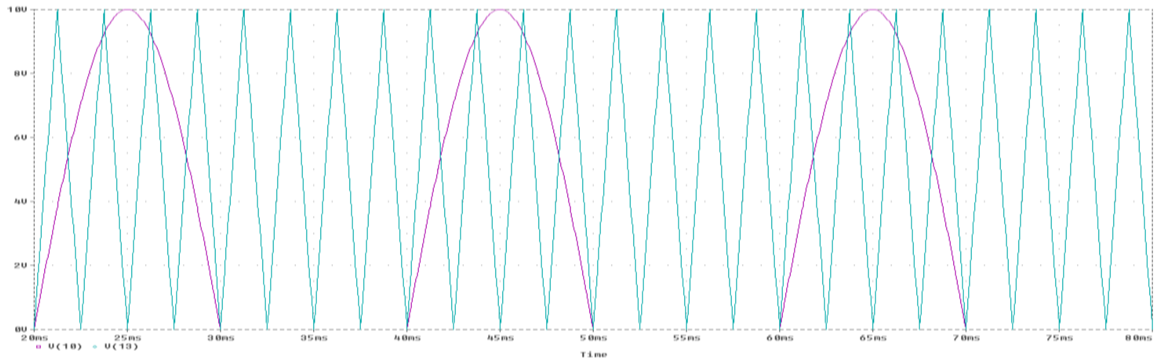
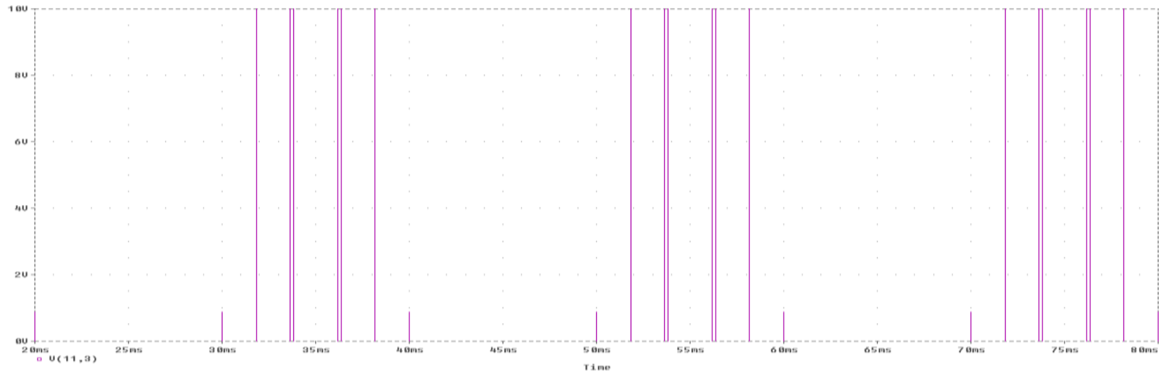
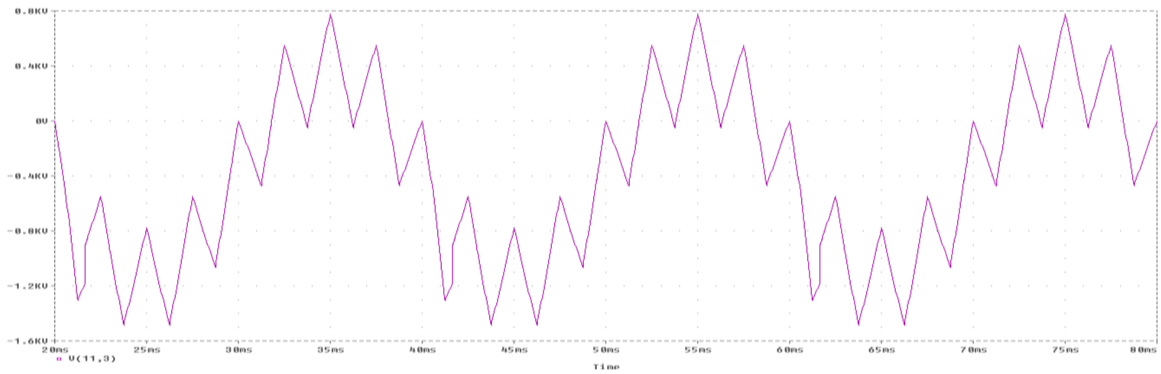


Figure 4. Waveform PWM with comparison of sinusoidal waves and triangles (4 pulses per half cycle)



(a)

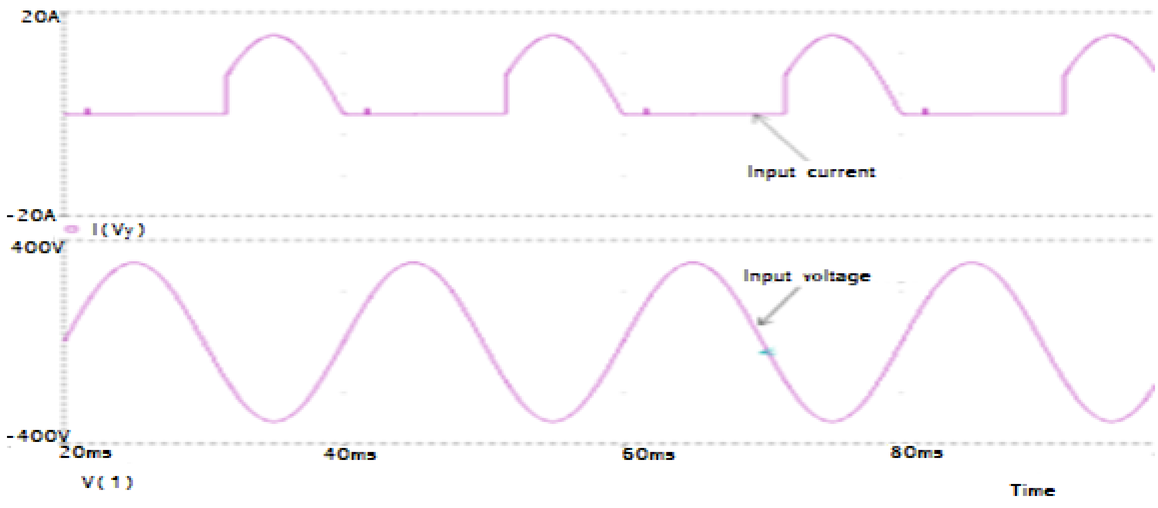


(b)

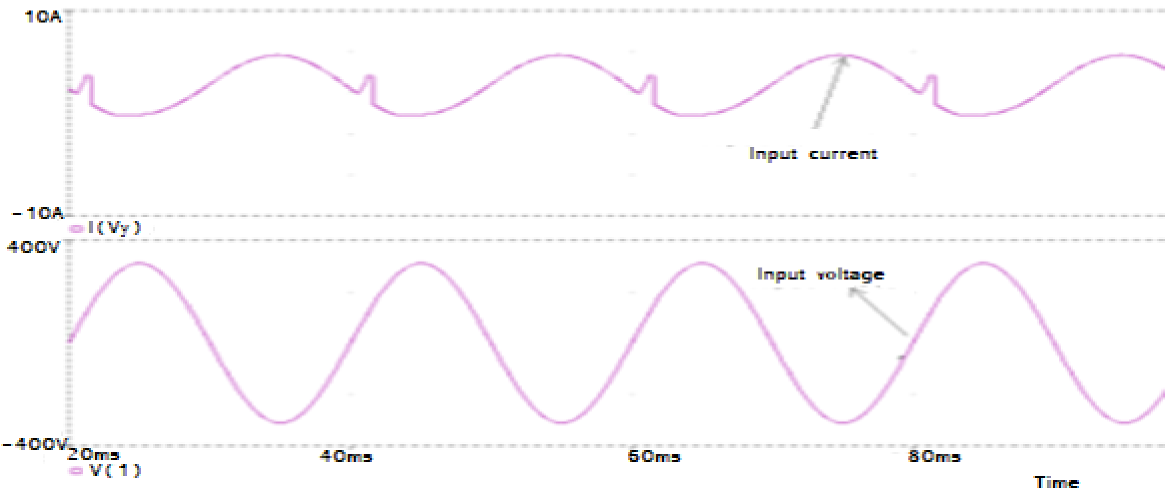
Figure 5. PWM waveform output (a) PWM pulse (4 pulses per half cycle), (b) PWM wave voltage output

3.1.1 Rectifier Controlled with R Load

Figure6 shows the ratio of the current waveform and the input voltage. In the simulation, an active filter rectifier with PWM control is better than an active filter with pulse control. Based on the appearance of two visible waveforms, the input current rectifier with an active filter shows that wave damage is relatively significant because of the high harmonics. Therefore, the PWM-controlled rectifier can reduce the harmonics so that the current appears close to the sinusoidal waveform.



(a)



(b)

Figure 6. Waveform current and input voltage of controlled rectifier with R load,
(a) Active filter (b) PWM control

The analysis is performed on the same power to find out the harmonic ratio generated by both rectifiers. There is a difference in output voltage; therefore, it must be reiterated to obtain the same power. Figure 7 compares Fourier input current components at a firing angle of 30^0. A harmonic reduction of 2 to 9 for a PWM control rectifier can be seen compared to an active filter rectifier. Based on the Fourier component obtained from the simulation result at 30^0 firing angle, it is obtained:

- Displacement angle (φ1) = -162.80.
- Power factor (before THD, cos φ1)
  = Cos (-162.80) = 0.95 (lead).
- Total Harmonic Distortion (THD) = 10.83%
- Power factor (after THD):

$$PF = \sqrt{(1-0.1083)^2}\, cos0.95 = 0.94\ (lead)$$

3.1.2 Rectifier Controlled with RL Load

As a comparison, both rectifiers are given RL loads and simulated with the same method to obtain the harmonic effect on the input voltage. Figure8 shows the comparison of both rectifiers. A rectifier with PWM control shows a harmonic reduction effect compared to an active filter. The current input on the Rectifier with the active filter shows a defect high enough that the current waveform is not as sinusoidal. This condition significantly affects the electrical distribution network, which causes the power factor to decrease, and it can increase the reactive load.

Similarly, harmonic input analysis is also performed on both rectifiers with RL load. Tables 1 and 2 indicate that Total Harmonic Distortion

(THD) in the Rectifier is controlled with the active filter of 106.4%, while the Rectifier with PWM control obtained THD of 25.48%. There are many significant harmonic reductions of the PWM control effect. The increase of THD in the input voltage affects the power factor of the Rectifier. Figure9 compares power factor graphs before and after the effect of THD on both rectifiers.

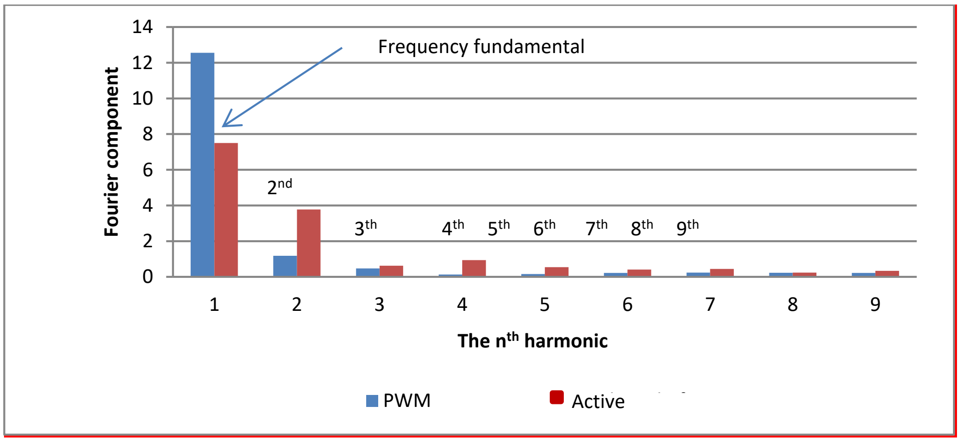
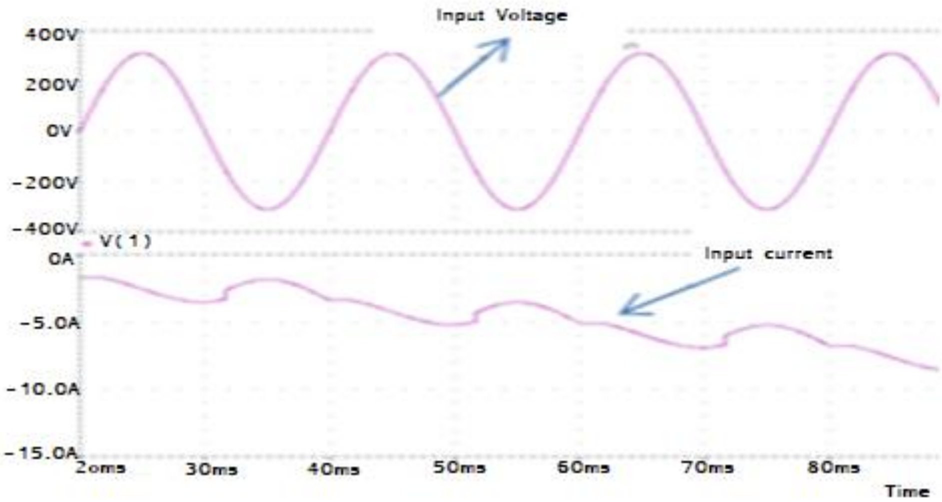
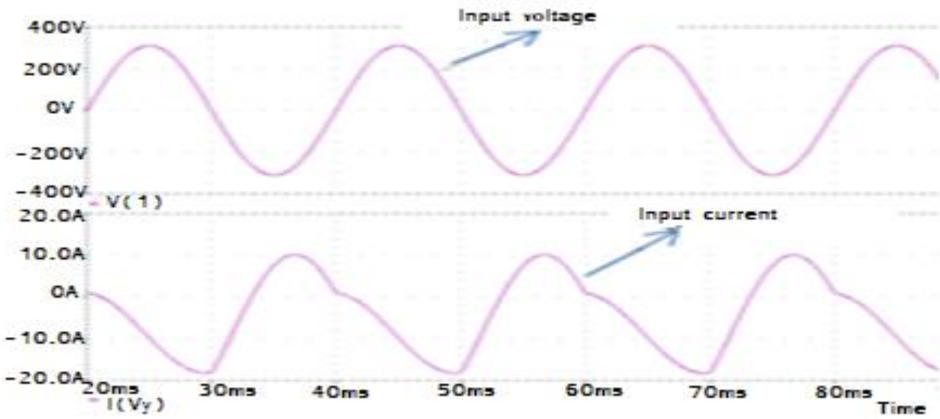


Figure 7. Comparison of harmonic reduction of both rectifiers with R load



(a)



(b)

Figure 8. Waveform input current and voltage of controlled rectifier with RL load,
(a) Active filter (b) PWM control

Table 1. Fourier Components and input current at 30^0 firing angle on PWM control

FOURIER COMPONENTS OF TRANSIENT RESPONSE I(VY)
DC COMPONENT = -3.901936E+00

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	1.290E+01	1.000E+00	1.322E+02	0.000E+00
2	1.000E+02	3.210E+00	2.488E-01	-8.960E+01	-2.218E+02
3	1.500E+02	2.192E-02	1.699E-03	-3.723E+01	-1.694E+02
4	2.000E+02	6.462E-01	5.009E-02	-9.014E+01	-2.223E+02
5	2.500E+02	9.584E-03	7.428E-04	-4.197E+01	-1.741E+02
6	3.000E+02	2.728E-01	2.114E-02	-9.168E+01	-2.238E+02
7	3.500E+02	6.525E-03	5.058E-04	-8.867E+00	-1.410E+02
8	4.000E+02	1.458E-01	1.130E-02	-9.269E+01	-2.248E+02
9	4.500E+02	9.186E-03	7.120E-04	5.833E+00	-1.263E+02

TOTAL HARMONIC DISTORTION = 2.548923E+01 PERCENT

Table 2. Fourier components and input current at 30^0 firing angle on active filter

FOURIER COMPONENTS OF TRANSIENT RESPONSE I(VY)
DC COMPONENT = -1.261488E+02

HARMONIC NO	FREQUENCY (HZ)	FOURIER COMPONENT	NORMALIZED COMPONENT	PHASE (DEG)	NORMALIZED PHASE (DEG)
1	5.000E+01	5.913E+00	1.000E+00	1.119E+02	0.000E+00
2	1.000E+02	5.352E+00	9.051E-01	-4.696E+01	-1.589E+02
3	1.500E+02	2.274E+00	3.846E-01	7.330E+00	-1.046E+02
4	2.000E+02	1.305E+00	2.207E-01	-4.204E+01	-1.539E+02
5	2.500E+02	1.525E+00	2.578E-01	-2.054E+00	-1.140E+02
6	3.000E+02	5.144E-01	8.700E-02	-1.075E+01	-1.227E+02
7	3.500E+02	1.022E+00	1.728E-01	-1.542E+01	-1.273E+02
8	4.000E+02	5.745E-01	9.716E-02	2.038E+01	-9.152E+01
9	4.500E+02	5.946E-01	1.006E-01	-2.434E+01	-1.362E+02

TOTAL HARMONIC DISTORTION = 1.06408E+02 PERCENT

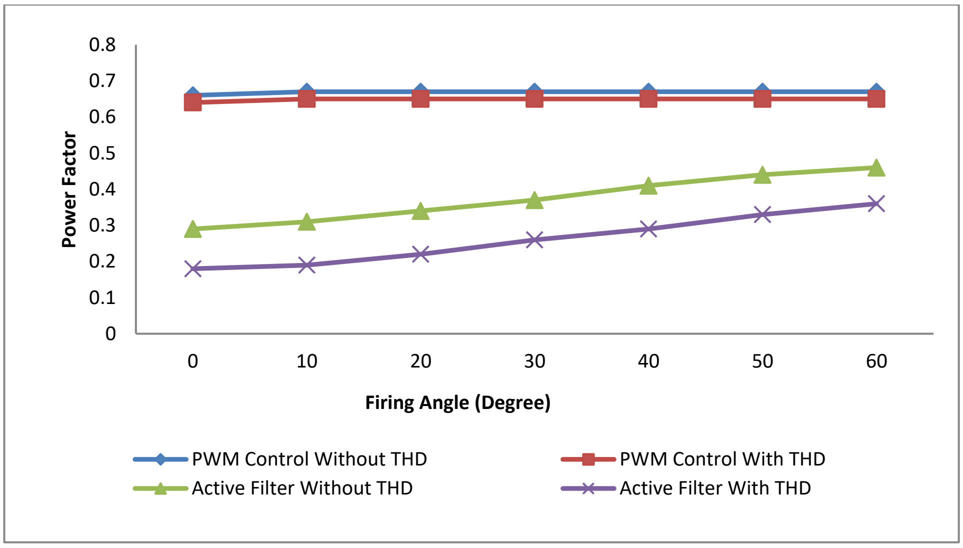


Figure 9. Comparison of power factor before and after THD effects

3.2 Discussion

Electronic equipment forms a significant part of the load on the utility. Most power conversion electronics equipment consists of an AC-to-DC conversion stage immediately following the AC source. An AC-to-DC converter has become an integral part of mostly all electronic equipment. Two factors that provide a quantitative measure of the power quality in an electrical system are PF and THD. The PF of the system predominantly decides the amount of helpful power consumed by an electrical system. In this study, we have performed a rectifier simulation with R and RL load. Based on the simulation results show that the PF and THD of the rectifier are affected by the load performance used. However, when the active filter is controlled with PWM on a rectifier, it can reduce the harmonic (THD) and PF of the rectifier increase. In addition, PSPICE software can be used to analyze PF and THD on converters. It has the advantage of making an easy netlist, simple and high accuracy.

The power factor correction on the rectifier with the active filter having only one pulse is performed using a PWM control. Four pulses per half cycle are performed by forming input phase currents into discontinuous waveforms. The more pulses are given on the bases of the active component, can increase the PF that impacts the phase currents approaching the sinusoidal form. The same thing has been revealed by [25] through a Matlab simulation of a 3-pulse and 12-pulse PWM rectifier. The best result of ripple factor, efficiency, and unitary input power factor at mains input, reduced harmonics, and the regulated output voltage was obtained using twelve PWM rectifier pulses. Because the number of pulses increases the harmonics reduction will be better and therefore better DC link output voltage is achieved.

4. CONCLUSION

Two different configurations have been simulated in the PSPICE program to analyze the power factor correction of controlled and THD rectifiers. The first configuration uses a single pulse control on the active filter. The simulation results show that adding four pulses with PWM control on the active filter can reduce harmonics and increase the PF of the Rectifier. In the RL load, the THD in the Controlled Rectifier with an active filter is 106.4%, while in the PWM control, the THD is 25.48%. Likewise, the power factor has increased from 0.25 (active filter) to 0.65 (PWM control).

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