A COMPARISON ANALYSIS OF SINGLE-PHASE RECTIFIER WITH ACTIVE FILTER AND PWM CONTROL USING PSPICE SIMULATION

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Abstract: *A PWM control on the active filter for a single phase controlled rectifier is proposed in this paper. This is done as a comparative study, using two different converters at one pulse control and PWM control (4 pulses) of the active filter. Both converters are given the same R and RL loads to obtain a comparison of power factor (PF) and Total Harmonic Distortion (THD). Simulation for this technique has been performed by using the PSPICE simulation program. The performance of the two rectifiers has been evaluated on the basis of an input current waveform, THD, and PF. The simulation results showed that the addition of 4 pulses with PWM control on the active filter can reduce harmonics and it can improve the PF on the rectifier.*

Key words: *THD, Power Factor, Simulation, Pulse Width Modulation.*

1. Introduction

In recent years, the harmonics in the power system are serious due to the wide applications of the electronic equipment in which the AC/DC converter are usually used. Traditionally, Solid State Frequency Converters (SSFC) have used Silicon Controlled Rectifiers (SCR) or Thyristor to convert AC power to DC power. By the use phase control, average values of load voltage can be controlled and varied [1-4]. SCR's have the advantage of being easy to control and inexpensive. They just 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) shows that a controlled rectifier produces high harmonic distortions in the input current waveform and a very low power factor. That is, they lower the input power factor taking more reactive current and they induce 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 more generally electrical pollution.

A lot of efforts have been performed to reduce harmonic contents in the input voltage of the controlled rectifier. Passive filters have been used by many researchers with different configurations [7-10], but this technique suffers from bulky, heavy filter elements and sometimes causes resonance problems. Alternatively, the peoples have developed active filters as an attractive option, but these techniques suffer from complexity and high costs [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, it is very difficult to do low harmonic filtering. In [15, 16] proposed a hybrid type using active filters and passive filter to improve passive filter performance. However, this scheme suffers from bulky construction, resonant problems, and the current in the injection branch is very sensitive to the deviation of the *L* and *C* values.

A new technique has been developed by several previous studies with Pulse Width Modulation (PWM) controls. This method allows creating 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, concentrating on PWM control schemes, have been made to improve the input current distortions. In [18, 19] conducted the concerns a variable switching frequency PWM. With this PWM, the switch in the rectifier works in such a way that when the rectifier dc-side current falls to zero, the switch is turned on again immediately. However, this control scheme suffers from a serious defect; namely, the switching frequency is load-dependent. A lighter load, the increase of switching frequency results 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, there are several simulation models performed by the researchers. A detailed analysis for determining the relation between the optimal amplitude and phase angle of the injection current along with the firing angle has been carried out with PSIM simulation [20]. By MATLAB software, Venkatesh's presents the modeling and simulation of both 6-pulse and 12-pulse rectifier topologies to compare their input current harmonics, output voltage ripples and also total Harmonic Distortion (THD) as well [21]. In [22] comparison of performance for 3 pulses and 12 pulse, PWM rectifiers are done. They are also using Matlab/Simulation model. Meanwhile, A. Zammouri, et al [23] has 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 the PWM control. These researchers and the ideas shown in this research show the superiority of this technique in reducing the harmonic contents of line currents and increasing the power factor of the controlled rectifier of a single phase. The system is investigated in this paper is single-phase full-wave controlled bridge rectifier. Circuit diagram, mathematical expressions, and voltage and current waveforms are presented for each rectifier when feeding the following loads:

1. Resistive load, R
2. Resistive, R, and inductive, L, load

2. Methods and Materials

2.1 Modeling simulation and rectifier circuit specification

PSPICE software release 7.1 used in this study. Fig.1 and 2 show the rectifier circuit to be simulated with different loads. 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.

2.2 Data Analysis

In accordance with the purpose of this study, then we perform data analysis based on descriptive statistical studies in the form of percentage value and find the average value based on the simulation results. Power factor is determined by the equation:

$$PF = \sqrt{(1 - THD)^2} \text{ x } \cos \emptyset \quad (1)$$

To calculate the effective value (RMS) AC component output voltage, used the following equation:

$$V_{AC} = \sqrt{V_{RMS}{}^2 - V_{DC}{}^2} \quad (2)$$

Then the ripple factor is determined by:

$$RF = \frac{V_{AC}}{V_{DC}} \; x \; 100\% \quad (3)$$

Output load power as follows:

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

and,

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

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

$$\eta = \frac{P_{DC}}{P_{AC}} \; x \; 100\% \quad (6)$$

3. Result and Discussion

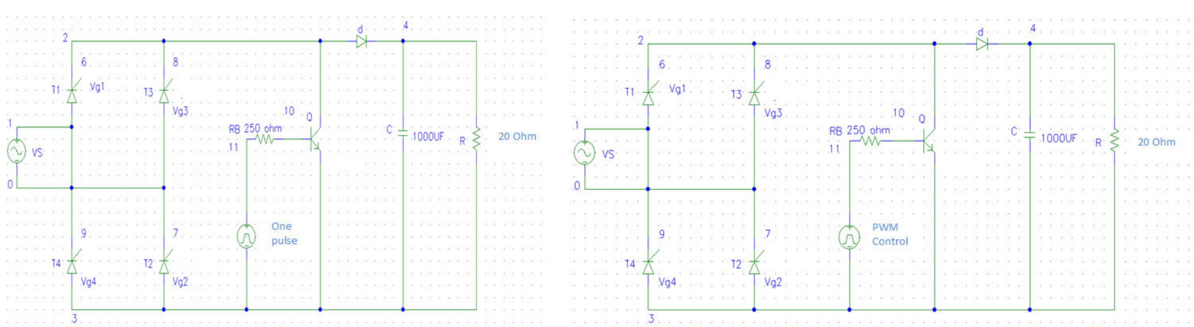
3.1 Use of PSPICE on PWM control

There are two ways to use PSPICE

programming packages for simulators, by using the schematic sub-program and the program netlist written based on the definition of the circuit. In this research used netlist to simulate the performance of single phase controlled rectifier. The output of the simulation is waveform and numerical data. The waveform observed is the output voltage waveform, input voltage and load current. While the numerical data studied is the input and output voltage harmonics after controlled PWM, current harmonics, PF and THD. Fig. 3, and 4 illustrates a PWM waveform input and output with a comparison of sinusoidal waves and triangles (4 pulses per half cycle)

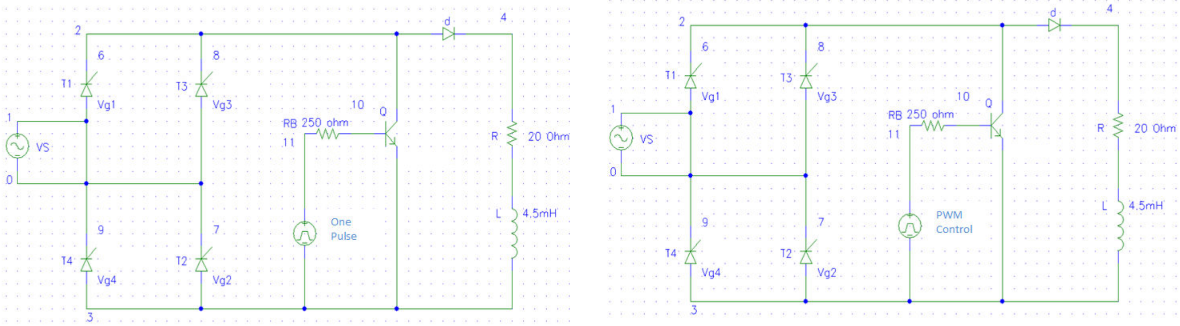
The netlist of the PSPICE program has been compiled as follows:

```
* 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
```



(a) (b)

Fig. 1. Single phase controlled rectifier circuits with R load, (a) one pulse, (b) PWM control (4 pulse per a half cycle)



(a) (b)

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

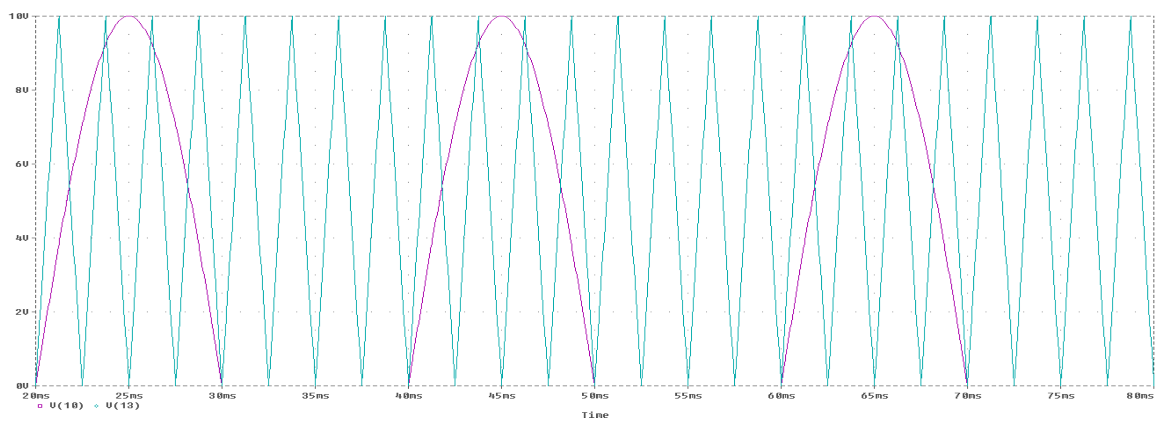
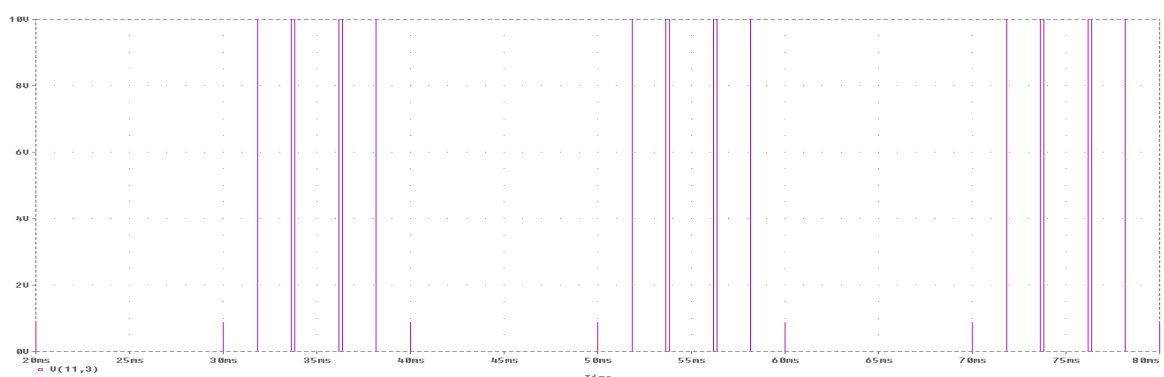
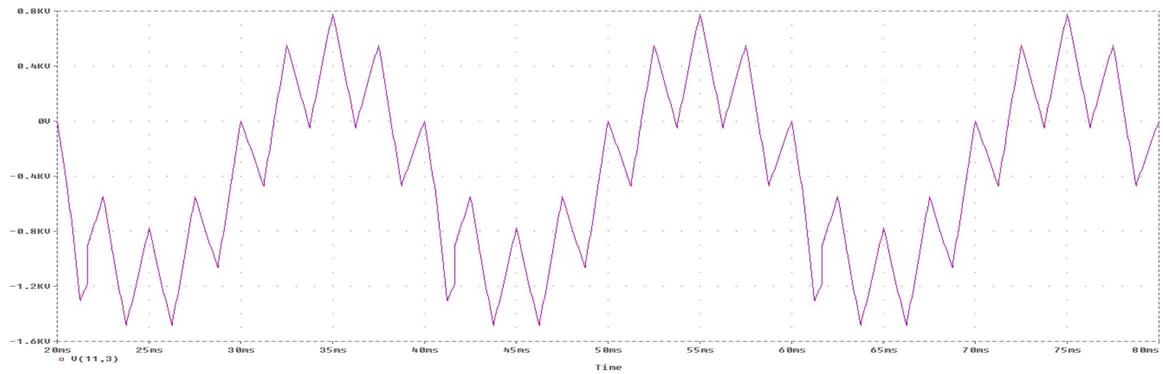


Fig. 3. Waveform PWM with comparison of sinusoidal waves and triangles (4 pulses per half cycle)



(a)



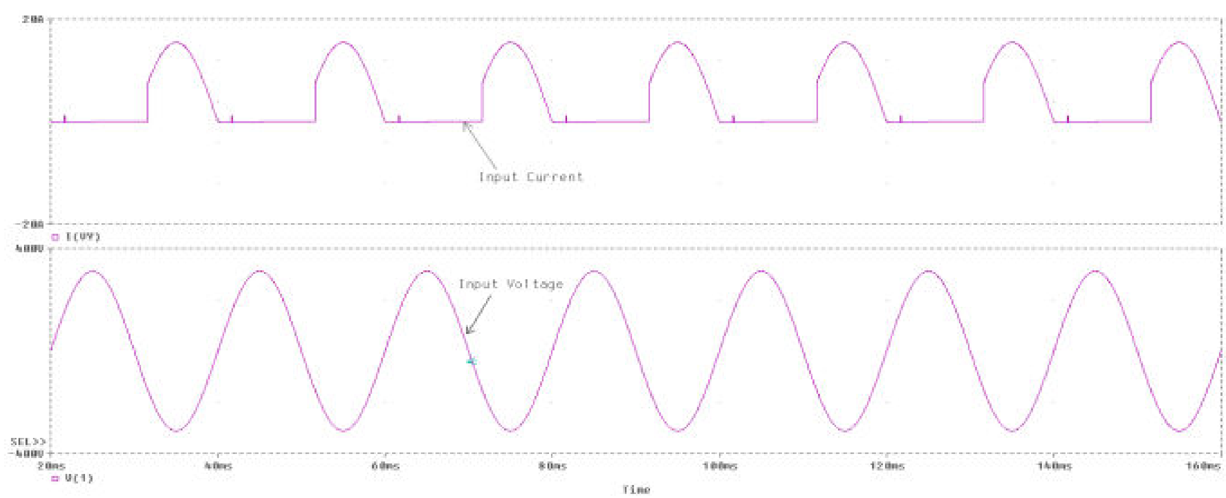
(b)

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

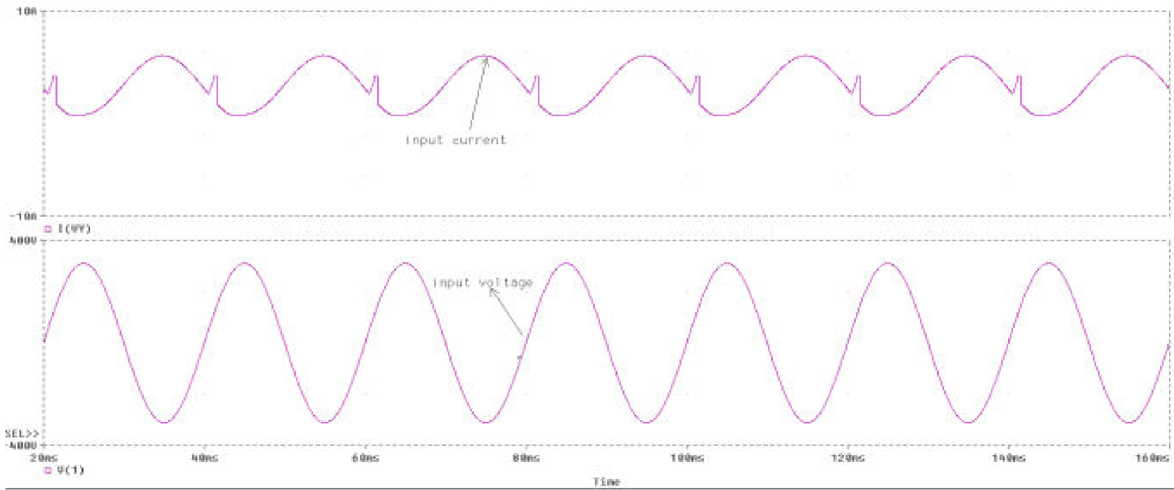
3.2 Simulation

3.2.1 Rectifier Controlled with R Load

Fig. 5 shows the ratio of the current waveform and the input voltage. It can be seen that in simulation an active filter rectifier with PWM control is better than an active filter with a pulse control. Based on the appearance of two visible waveforms, the input current rectifier with active filter seen the existence of wave damage is quite high because of the high harmonics that occur. Therefore, the PWM-controlled rectifier can reduce the harmonics so that the current appears close to the sinusoidal waveform.



(a)



(b)

Fig. 5. Waveform current and input voltage of controlled rectifier with R load, (a) Active filter, (b) PWM control

To find out the harmonic ratio generated by both rectifiers, the analysis is performed on the same power. There is a difference in output voltage, therefore, it has to be reiterated in order to obtain the same power. Fig. 6 shows the comparison of Fourier input current components at a firing angle 30^0. As can be seen, a harmonic reduction of 2 to 9 for a PWM control rectifier 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):

$$= \frac{1}{\sqrt{1+(THD)^2}} \text{ x} \cos \theta_1 = \frac{1}{\sqrt{1+(0{,}108)^2}} \text{ x } 0.95 = 0.94 \ (\textit{lead})$$

3.2.2 Rectifier Controlled with RL Load

As a comparison, both rectifiers are given RL loads and with the same method simulated to obtain the harmonic effect on the input voltage. Fig. 7 shows the comparison of both rectifiers. It can be seen, 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 greatly 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) that occurs in the rectifier is controlled with active filter of 100.67%, while the rectifier with PWM control is obtained THD of 25.48%. That is, 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. Fig. 8 shows the comparison of power factor graphs before and after the effect of THD on both rectifiers.

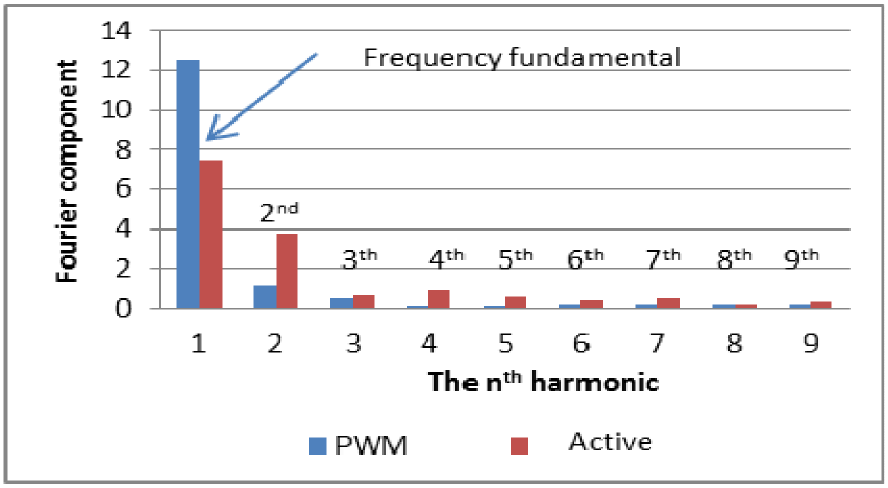
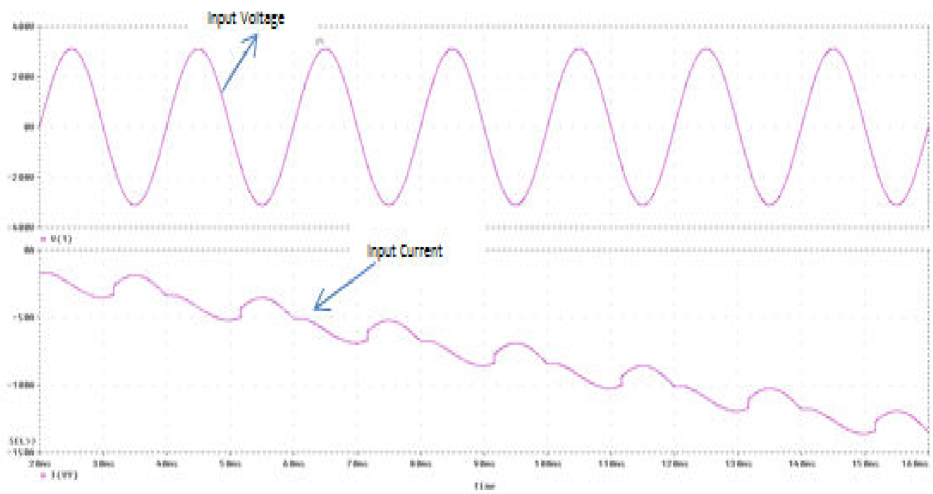
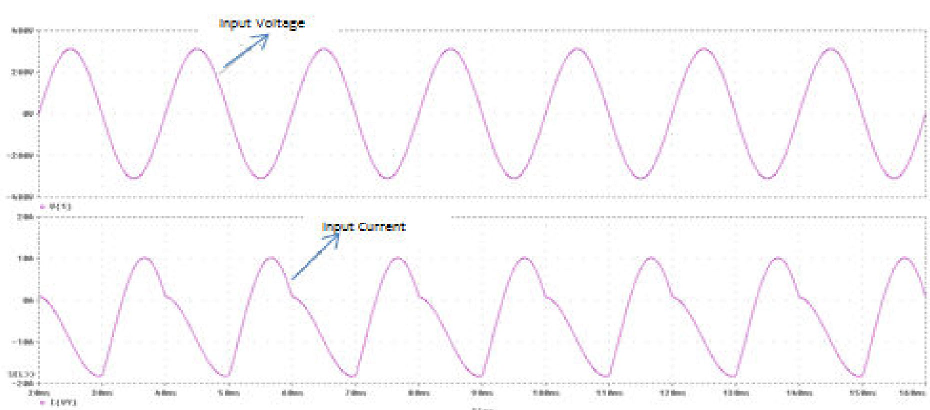


Fig. 6. Comparison of harmonic reduction of both rectifiers with R load



(a)



(b)

Fig. 7. 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 = 1.067408E+02 PERCENT

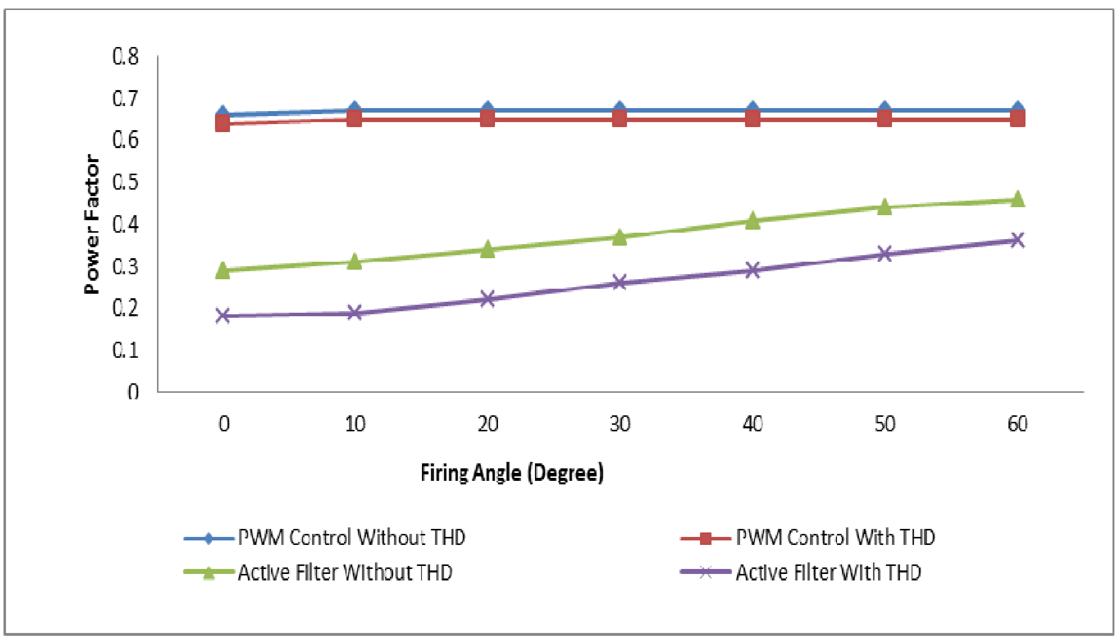


Fig. 8. Comparison of power factor before and after THD effects

3.3 Discussion

The electronic equipment forms a major 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. Thereby an AC to DC converter has become an integral part of mostly all the electronic equipment's. Two factors that provide a quantitative measure of the power quality in an electrical system are Power Factor (PF) and Total Harmonic Distortion (THD). The amount of useful power being consumed by an electrical system is predominantly decided by the PF of the 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, an easy netlist is made, 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 where 4 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, it can increase the PF that impacts the phase currents approaching the sinusoidal form.

4. Conclusion

Two different configurations have been simulated in the PSPICE program to analyze power factor correction and THD of the controlled rectifier. First configuration by using a single pulse control on the active filter. In both, the loading of R and RL gives a poor performance compared to the PWM control. At RL load the input current distortion decreases drastically, with THD of 100.67%. In PWM control there is a reduction of harmonics with THD of 25.48%. The rectifier power factor in the active filter obtained PF of 0.25, whereas in PWM control there was an increase of PF of 0.65.

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