



DESIGN AND ANALYSIS OF PASSIVE FILTERS FOR SIX AND TWELVE PULSE RECTIFIERS

Design and Analysis of Passive Filters for 6 and 12 Pulse Rectifiers

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Abstract: Introduction of semi conductor devices has led to revolution in power industry in terms of conversion of power from ac to dc and vice versa. In spite of the fact that these converters behave as non linear load to power system injecting harmonics into the system, these are very commonly used with additional filtering equipment. In the proposed work, performance of six pulse and twelve pulse rectifiers were analyzed by connecting passive filters in parallel in MATLAB/Simulink and the passive filters were able to handle the harmonics injected by the rectifiers, power quality and reliability of the power system is improved.

Index Terms - Six Pulse Rectifiers, Twelve Pulse Rectifiers, Passive Filters, Single Tuned Filters, Double Tuned Filters.

I. INTRODUCTION

Electronic Devices such as Personal Computers, Mobile Phones etc, require DC Power for their functioning. DC power is not readily available except in the form of batteries, these can only provide the power for short duration of time. Furthermore charging the batteries also requires DC Power. Alternative Solution is to convert the ac power to dc power; the conversion of power is done through rectifiers. Rectifier is a circuit which converts ac power to dc power. Rectifier circuit can be composed of diodes, silicon controlled rectifiers (thyristors), IGBT, GTO, MOSFET etc, as the switches which process the input ac signal through their on and off operations and output a smooth dc signal. Due to switching operations of these devices harmonics are injected into the system. Rectifiers can be single phase or three phase depending upon the availability of supply. Conventional three phase rectifier consists of six diodes which are turned on and off in a pattern to get a smooth dc signal. A controlled output cannot be obtained from Diode Rectifier, so diodes are being replaced by controlled devices such as thyristors, IGBT, MOSFET, GTO etc, these are controlled by external pulses given to gate terminals depending upon the application. Depending on the number of switching devices used rectifiers are classified as six pulse rectifiers consisting of six switching devices either uncontrolled such as diodes or controlled such as Thyristors, IGBTs etc., which require six pulses and twelve pulse rectifiers consisting of twelve devices which require twelve pulses. Six pulse and twelve pulse rectifiers are generally used in HVDC transmission for conversion of three phase ac power to dc power which makes use of thyristors as switching devices. With the increase of number of pulses the input characteristics gets improved due to increase in number of devices. A twelve pulse rectifiers uses two six pulse rectifiers in parallel. One six pulse rectifier is connected to Y-Y and other is connected to Y- Δ of a three winding transformer to provide 30° phase shift between two rectifiers to eliminate 5th and 7th harmonics. The relation between harmonic order and the pulse number of these rectifiers can be given by,

$$h = np \pm 1 \quad (1)$$

where h: HarmonicOrder, p : PulseNumber,
n : integer

II. SIX PULSE RECTIFIER

A six pulse rectifier requires six gate pulses to turn on the switching devices for conversion of three phase ac power to dc power. During conversion process due to switching of devices this rectifier injects harmonics in to the system. The order of harmonics injected is given by Eq.1, by taking pulse number as 6 and n as 1,2,.. the values of h are 5, 7 and 11, 13. Taking into consideration of values of h, a Capacitor Bank, 5th Harmonic, 7th Harmonic and 11th Harmonic Passive filters were designed with different reactive power capacities in MATLAB/Simulink as shown in Fig.2. The following equations were used for designing the filters [1],

$$X_c = \frac{kV^2}{Q_c} \tag{2}$$

where, X_c : Capacitive Reactance, kV : Voltage in kV

Q_c : Reactive Power

$$X_c = \frac{1}{2\pi fC} \tag{3}$$

$$X_L = \frac{X_c}{h_n^2} \tag{4}$$

$$X_L = 2\pi fL \tag{5}$$

$$X_n = \sqrt{X_L X_c} \tag{6}$$

$$R_n = \frac{X_n}{Q} \tag{7}$$

where,

X_c : Capacitive Reactance, X_L : Inductive Reactance, C : Capacitance, f : Frequency, h_n : Order of Harmonic, L : Inductance, R_n : Resistance, Q : Quality Factor

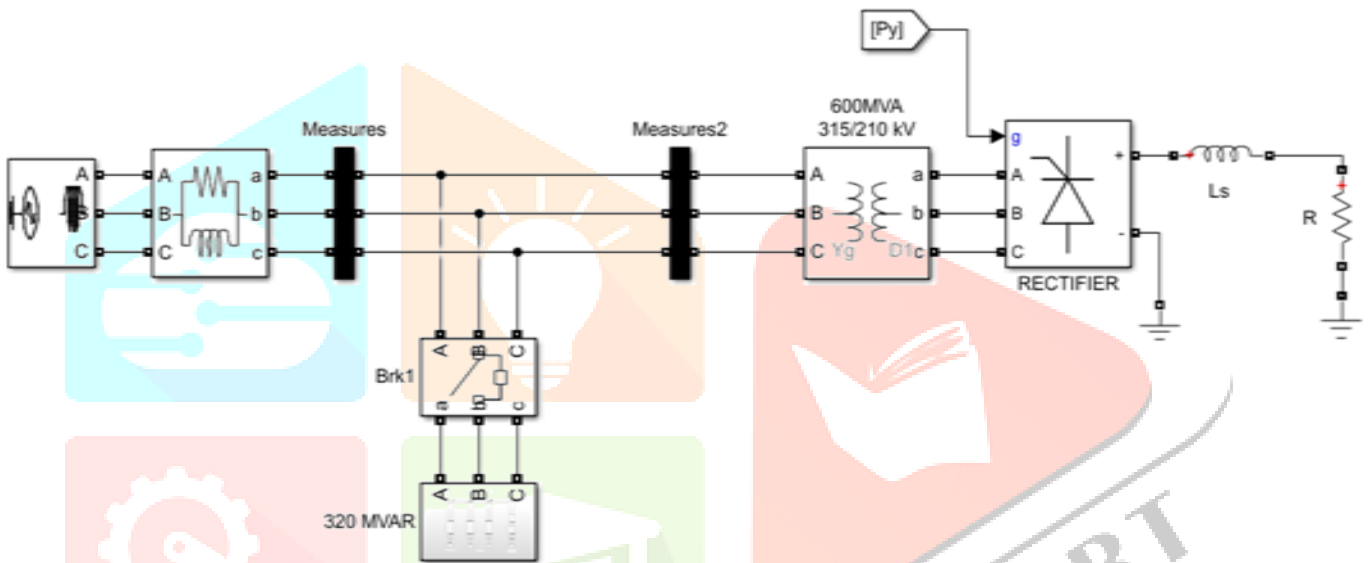


Figure 1 MATLAB/Simulink Model of Six Pulse Rectifier

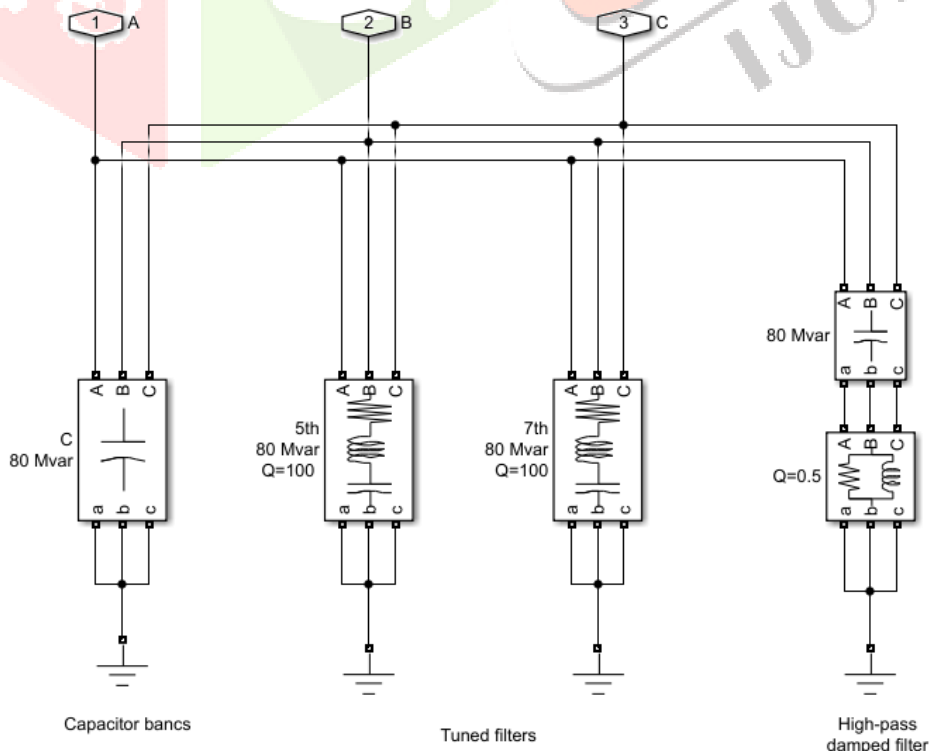


Figure 2 MATLAB/Simulink Model of Passive Filters for Six Pulse Rectifier

Table 1 Design Parameters of Passive Filters for Six Pulse Rectifier for 315kV, 50Hz

Passive Filters for Six Pulse Rectifier 315kV, 50Hz												
	320 MVAR				160 MVAR				80 MVAR			
	Capacitor Bank (80MVAR)	5 th Harmonic (80MVAR)	7 th Harmonic (80MVAR)	11 th Harmonic (80MVAR)	Capacitor Bank (40MVAR)	5 th Harmonic (40MVAR)	7 th Harmonic (40MVAR)	11 th Harmonic (40MVAR)	Capacitor Bank (20MVAR)	5 th Harmonic (20MVAR)	7 th Harmonic (20MVAR)	11 th Harmonic (20MVAR)
C	2.568 μ F	2.568 μ F	2.568 μ F	2.568 μ F	1.248 μ F	1.248 μ F	1.248 μ F	1.248 μ F	641.9 nF	641.9 nF	641.9 nF	641.9 nF
L		157.9 mH	80.59 mH	32.63 mH		315.9 mH	161.18 mH	65.27 mH		631.9 mH	322.43 mH	159.23 mH
R		2.48 Ohms	1.77 Ohms	225 Ohms		4.96 Ohms	3.54 Ohms	450.8 Ohms		9.92 Ohms	7.08 Ohms	902 Ohms

Table.1 shows the design parameters of Capacitor Bank, 5th Harmonic, 7th Harmonic and 11th Harmonic Filters with capacities of 320, 160 and 80 MVAR for a 315kV, 50Hz six pulse rectifier are computed using the equations from Eq.2 to Eq.7.

III. TWELVE PULSE RECTIFIER

A Twelve pulse rectifier requires twelve gate pulses to turn on the switching devices for conversion of three phase ac power to dc power. During conversion process due to switching of devices this rectifier injects harmonics in to the system. The order of harmonics injected is given by Eq.1, by taking pulse number as 12 and n as 1,2,.. the values of h are 11, 13 and 23, 25. Taking into consideration of values of h, a Capacitor Bank, C Type High Pass 3rd Harmonic, Double Tuned 11th & 13th Harmonic, High Pass 24th Harmonic Passive filters were designed with different reactive power capacities in MATLAB/Simulink as shown in Fig.4. The following equations were used for designing the filters,

$$X_c = \frac{kV^2}{Q_c} \quad (8)$$

where, X_c : Capacitive Reactance, kV : Voltage in kV , Q_c : Reactive Power

$$X_c = \frac{1}{2\pi f C_1} \quad (9)$$

For C-Type High Pass 3rd Harmonic Filter[2]:

$$C = \frac{(h^2-1)Q}{wV^2} \quad (10)$$

where h : Harmonic Order, Q : Reactive Power. $w = 2\pi f$, V : Voltage

$$L = \frac{V^2}{(h^2-1)Qw} \quad (11)$$

$$R = Q_f w_h L \quad (12)$$

For Double Tuned High Pass Filter (11th and 13th Harmonics)[3]:

Let C_a, L_a be the Capacitance and Inductance of 11th harmonic Filter

Let C_b, L_b be the Capacitance and Inductance of 13th harmonic Filter

$$C_1 = C_a + C_b \quad (13)$$

$$L_1 = \frac{1}{C_a W_a^2 + C_b W_b^2} \quad (14)$$

$$W_s = \frac{1}{\sqrt{L_1 C_1}} \quad (15)$$

$$W_p = \frac{W_a W_b}{W_s} \quad (16)$$

$$L_2 = \frac{\left(1 - \frac{W_a^2}{W_s^2}\right) \left(1 - \frac{W_b^2}{W_p^2}\right)}{C_1 W_a^2} \quad (17)$$

$$C_2 = \frac{1}{L_2 W_p^2} \quad (18)$$

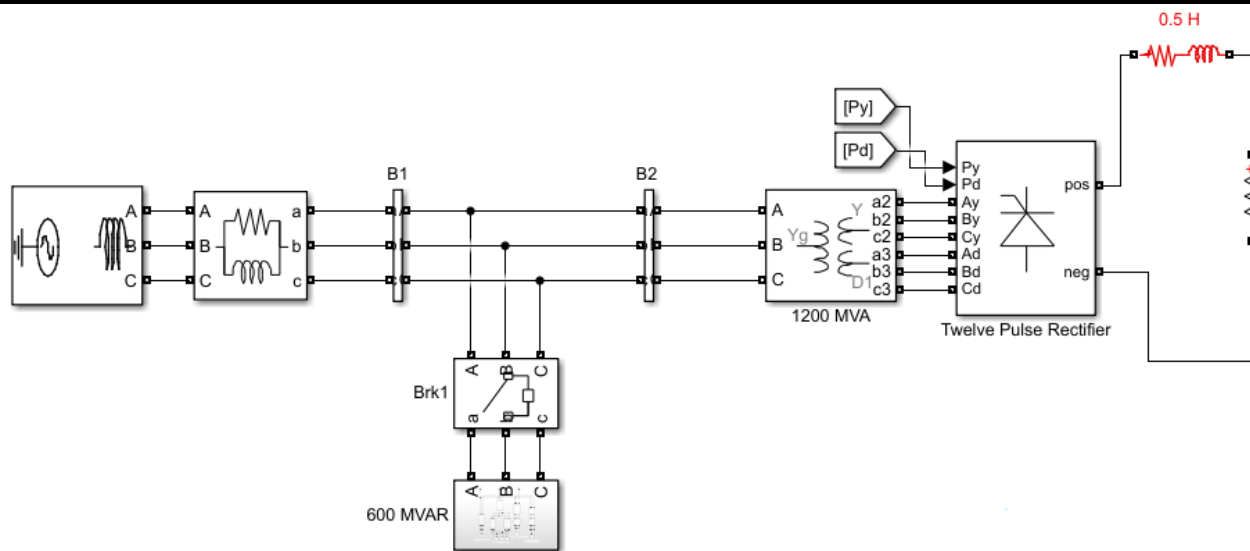


Figure 3 MATLAB/Simulink Model Twelve Pulse Rectifier

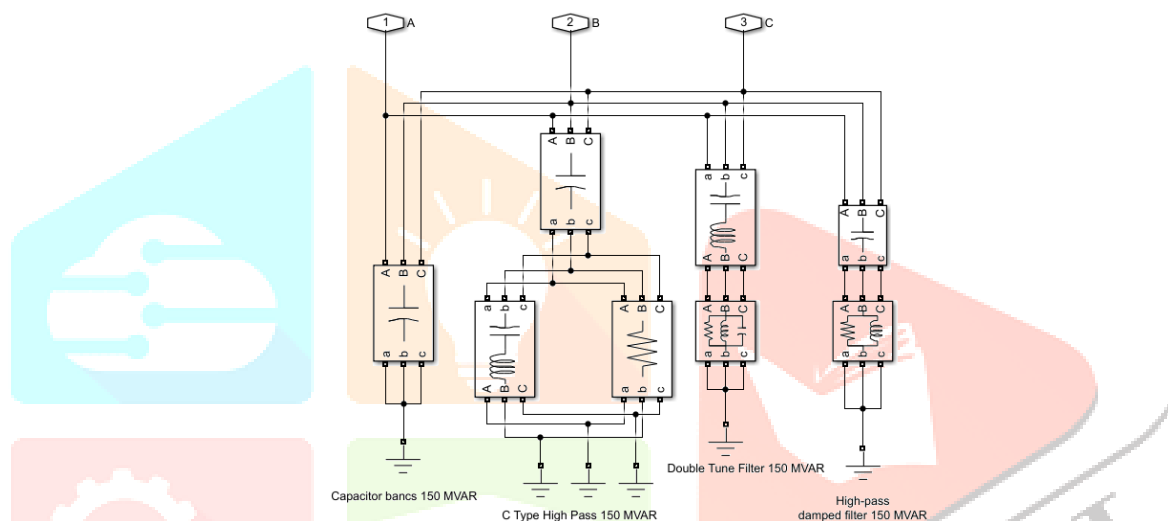


Figure 4 MATLAB/Simulink Model of Passive Filters for Twelve Pulse Rectifier

Table 2 Design Parameters of Passive Filters for Twelve Pulse Rectifier for 475kV, 50Hz

Passive Filters for Twelve Pulse Rectifier 475kV, 50Hz												
600 MVAR				300 MVAR				100 MVAR				
	Capacitor Bank (150 MVAR)	C Type High Pass 3 rd Harmonic (150MVAR)	Double Tuned 11 th & 13 th Harmonic (150MVAR)	High Pass 24 th Harmonic (150MVAR)	Capacitor Bank (75MVAR)	C Type High Pass 3 rd Harmonic (75MVAR)	Double Tuned 11 th & 13 th Harmonic (75MVAR)	High Pass 24 th Harmonic (75MVAR)	Capacitor Bank (25MVAR)	C Type High Pass 3 rd Harmonic (25MVAR)	Double Tuned 11 th & 13 th Harmonic (25MVAR)	High Pass 24 th Harmonic (25MVAR)
C	2.117 μF	16.93 μF		2.117 μF	1.058 μF	8.469 μF		1.058 μF	352.8 nF	2.823 μF		352.8 nF
C1		2.117 μF	4.234 μF			1.058 μF	2.116 μF			352.8 nF	705.6 nF	
L		598.79 mH		8.31 mH		1.197 H		16.62 mH		3.592 H		49.89 mH
R		1127 Ohms	65 Ohms	8.95 Ohms		2255 Ohms	130 Ohms	17.90 Ohms		6767 Ohms	380 Ohms	53.70 Ohms
C2			156.4 μF				77.04 μF				25.69 μF	
L1			16.52 mH				33.05 mH				99.13 mH	
L2			460 μH				933.9 mH				2.80 mH	

Table.2 shows the design parameters of Capacitor Bank using Eq.8 to Eq.9, C Type High Pass 3rd Harmonic using Eq.10 to Eq.12, Double Tuned 11th & 13th Harmonic using Eq.13 to Eq.18 and High Pass 24th Harmonic filters using Eq.2 to Eq.7 with capacities of 600, 300 and 100 MVAR for a 475kV, 50Hz twelve pulse rectifier are computed.

IV. SIMULATION

Six Pulse Rectifier and Twelve Pulse Rectifier designed are simulated in MATLAB/Simulink without passive filters and with 320, 160 & 80 MVAR filters for Six Pulse Rectifier and 600, 300 and 100 MVAR for Twelve Pulse Rectifier. Waveforms of Source Current, Source Voltage and Total Harmonic Distortions of Source Current and Source Voltage were analyzed.

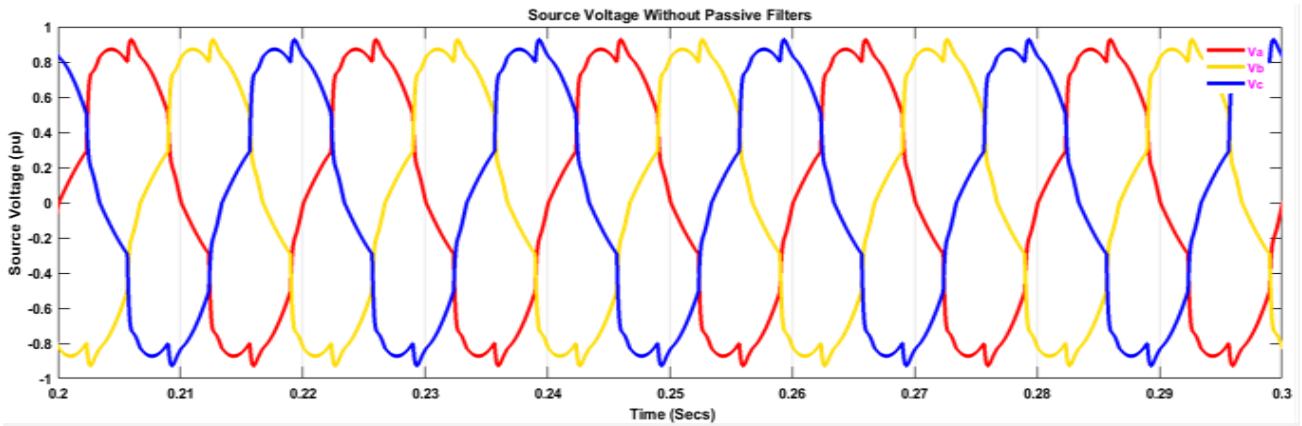


Figure 5 Source Voltage of Six Pulse Rectifier without Passive Filters

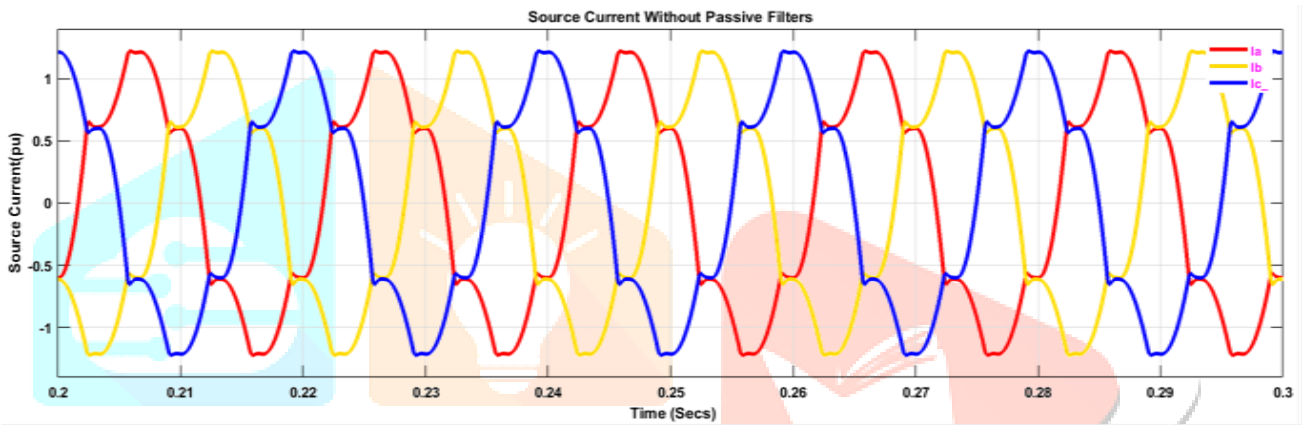


Figure 6 Source Current of Six Pulse Rectifier without Passive Filters

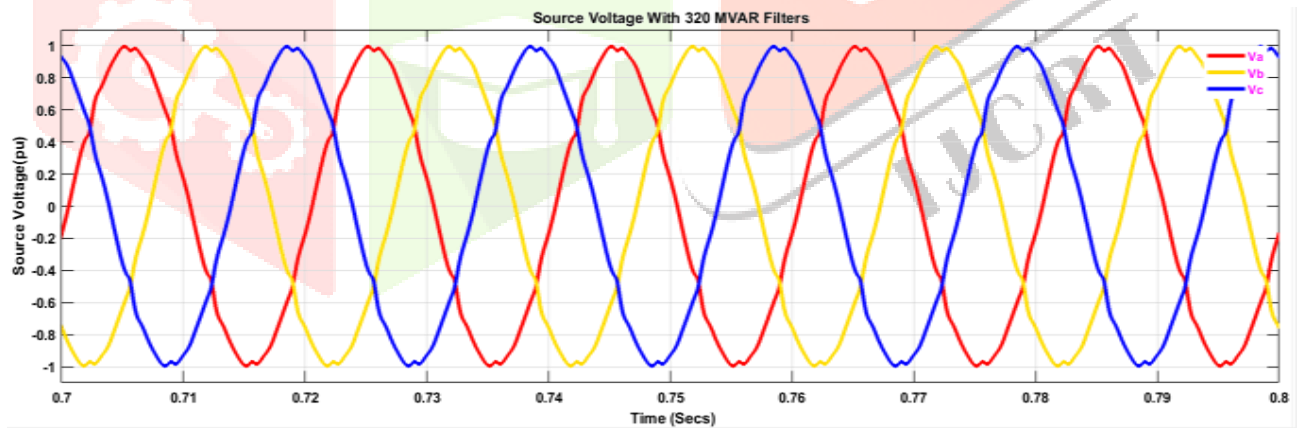


Figure 7 Source Voltage of Six Pulse Rectifier with 320 MVAR Passive Filters

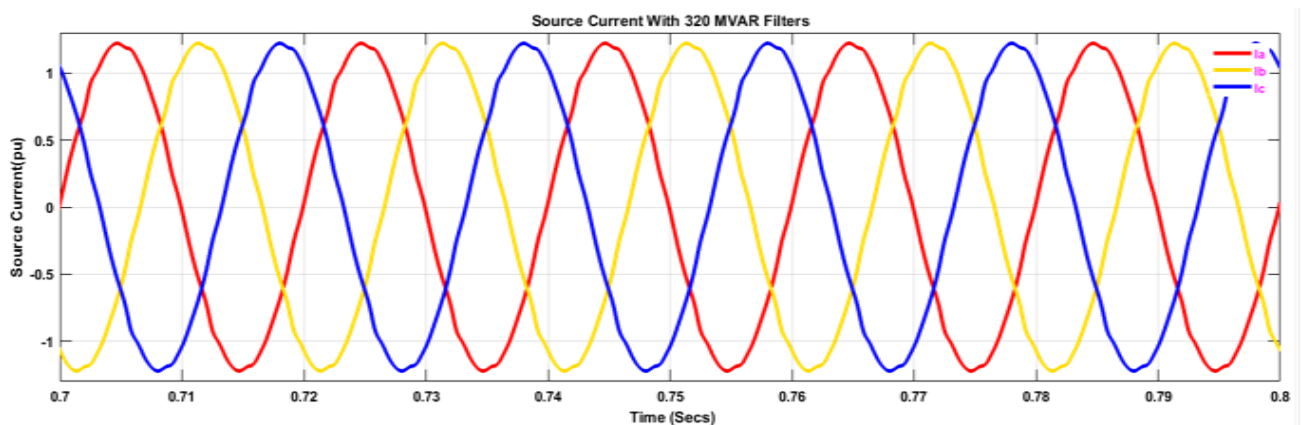


Figure 8 Source Current of Six Pulse Rectifier with 320 MVAR Passive Filters

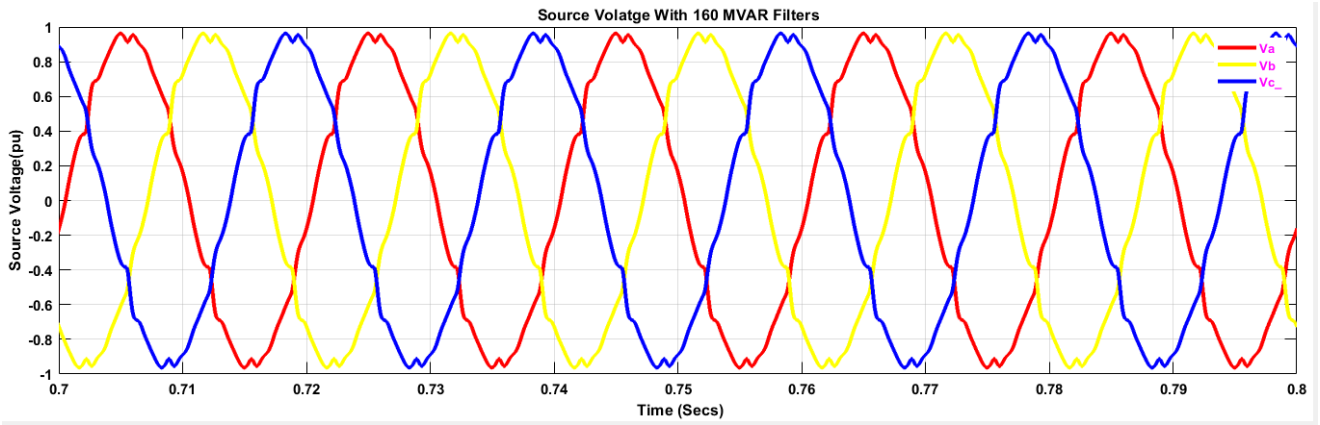


Figure 9 Source Voltage of Six Pulse Rectifier with 160 MVAR Passive Filters

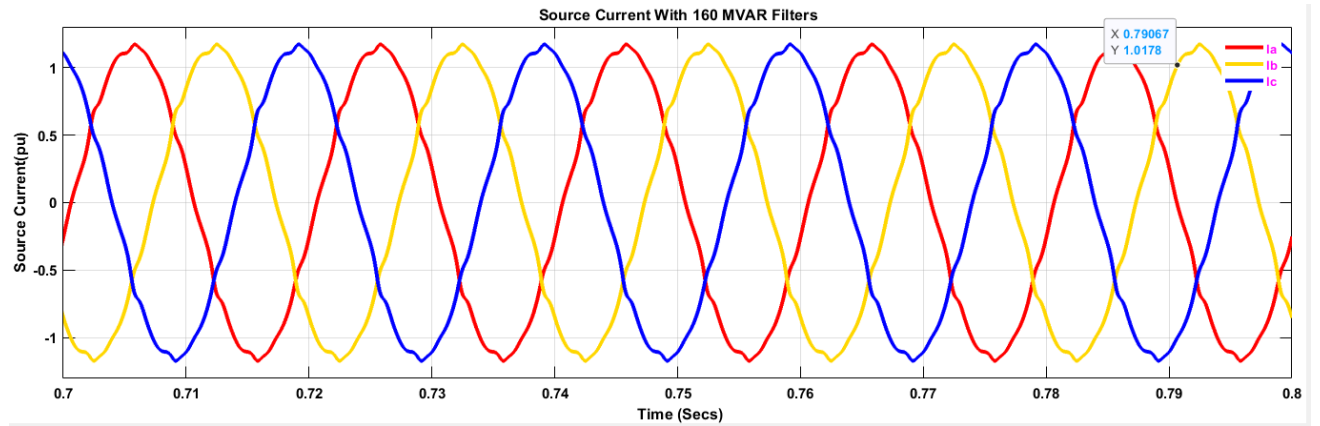


Figure 10 Source Current of Six Pulse Rectifier with 160 MVAR Passive Filters

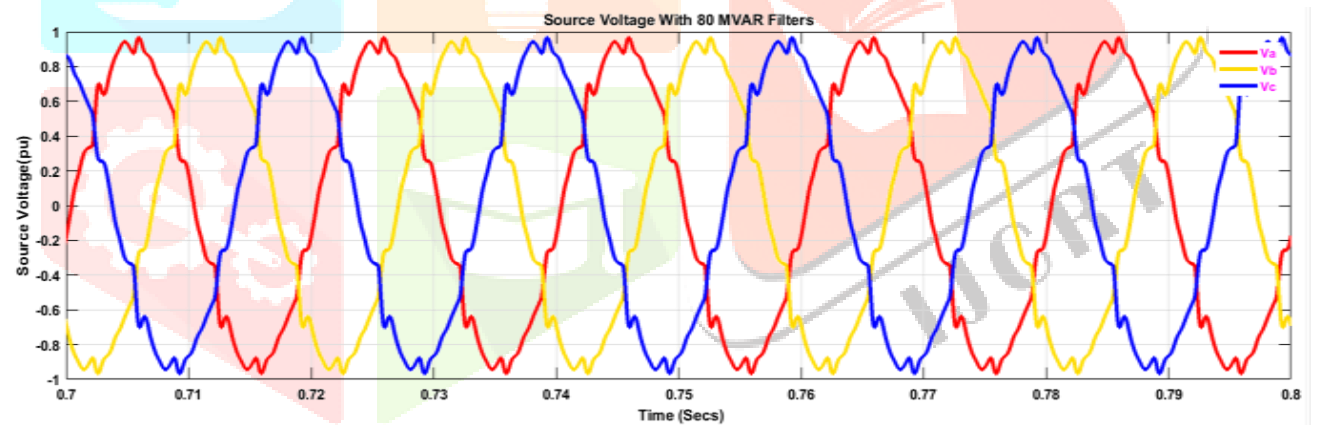


Figure 11 Source Voltage of Six Pulse Rectifier with 80 MVAR Passive Filters

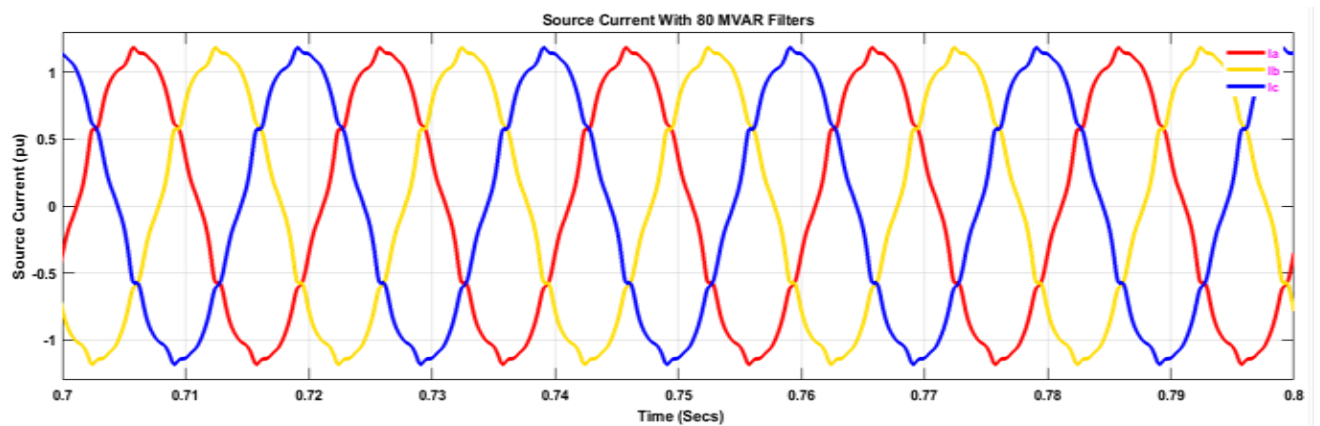


Figure 12 Source Current of Six Pulse Rectifier with 80 MVAR Passive Filters

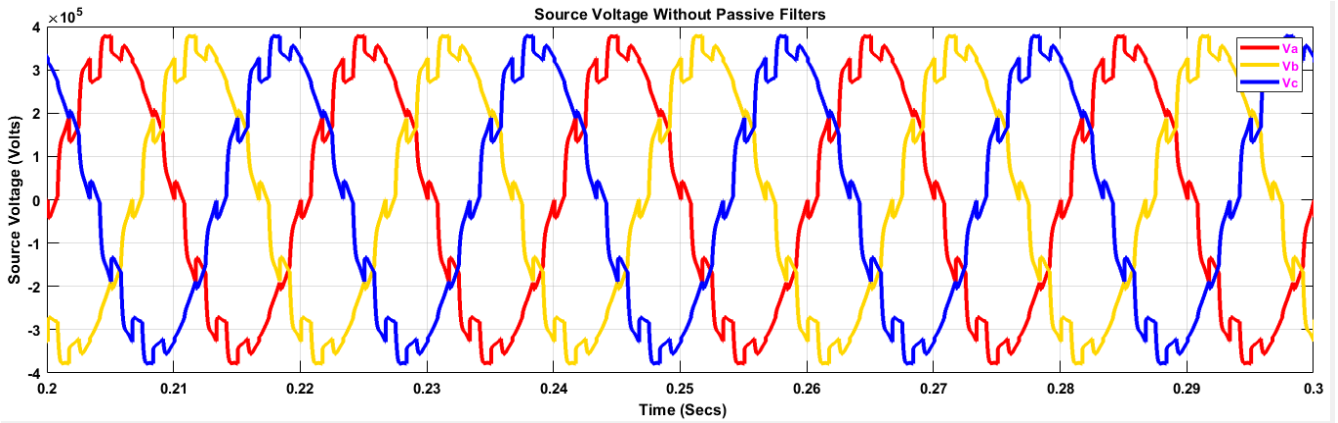


Figure 13 Source Voltage of Twelve Pulse Rectifier without Passive Filters

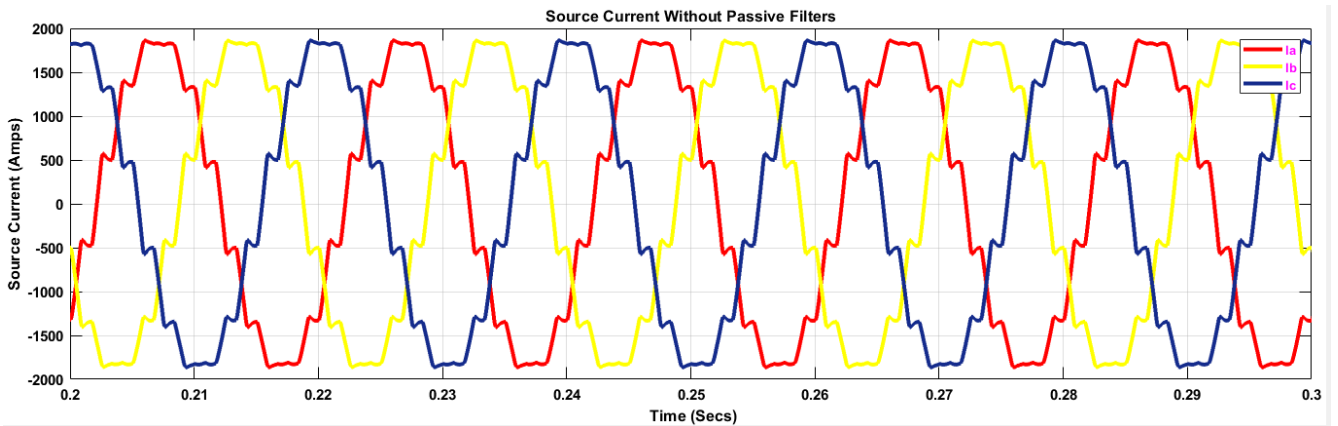


Figure 14 Source Current of Twelve Pulse Rectifier without Passive Filters

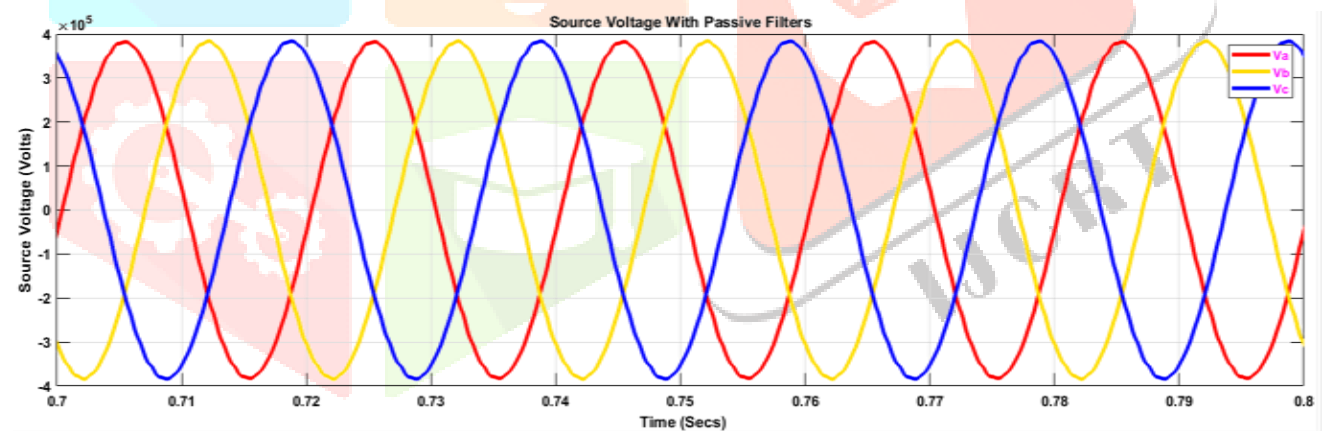


Figure 15 Source Voltage of Twelve Pulse Rectifier with 600 MVAR Passive Filters

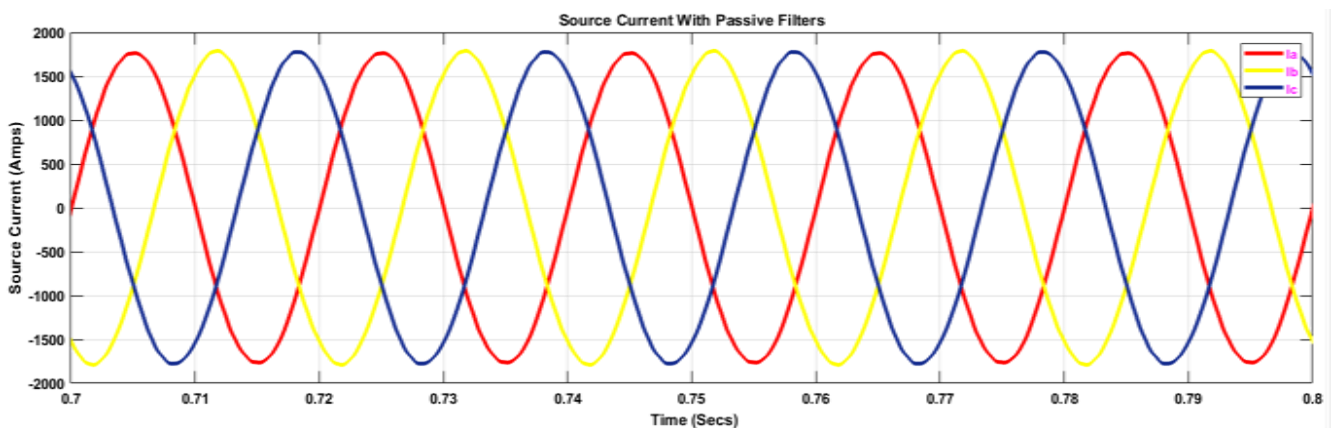


Figure 16 Source Current of Twelve Pulse Rectifier with 600 MVAR Passive Filters

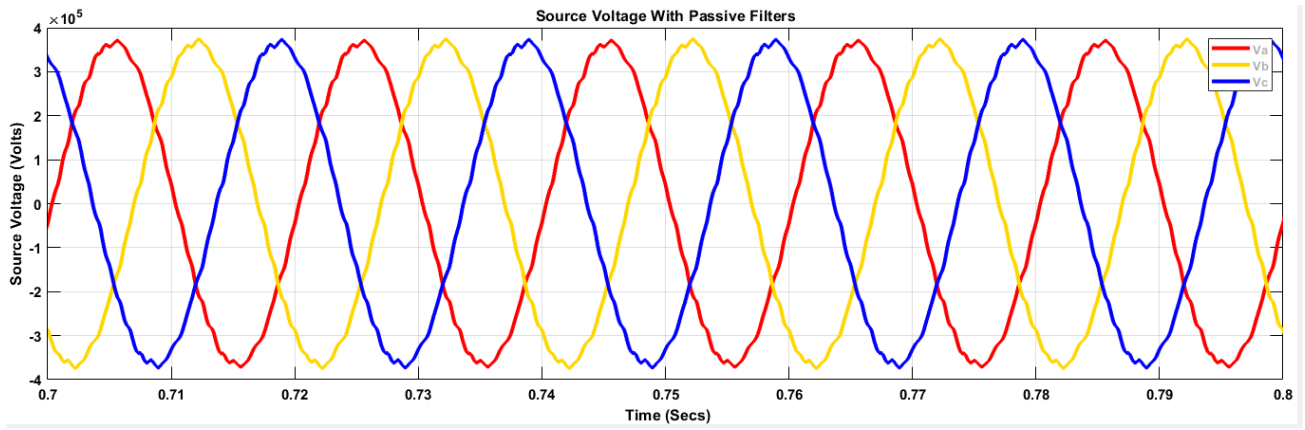


Figure 17 Source Voltage of Twelve Pulse Rectifier with 300 MVAR Passive Filters

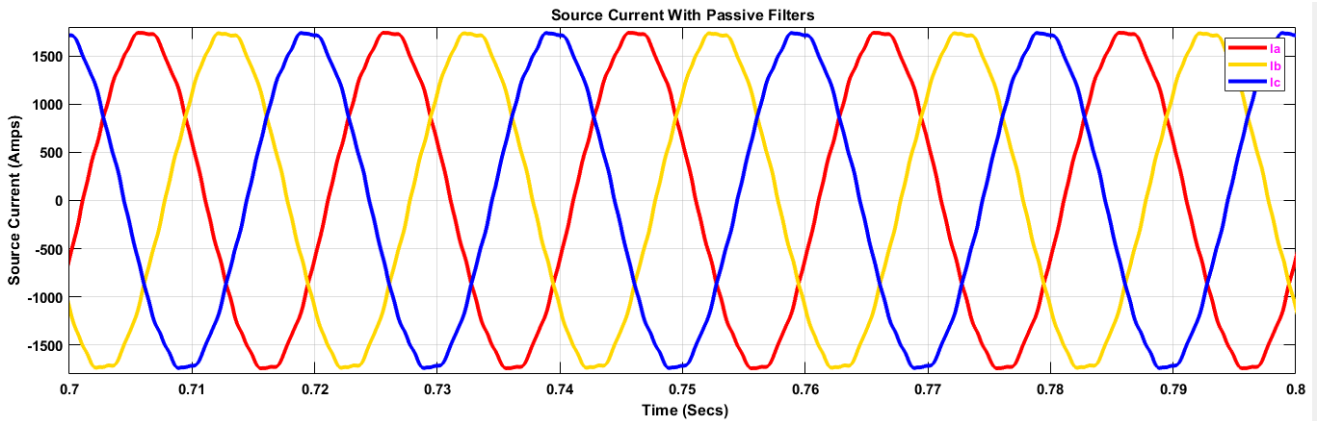


Figure 18 Source Current of Twelve Pulse Rectifier with 300 MVAR Passive Filters

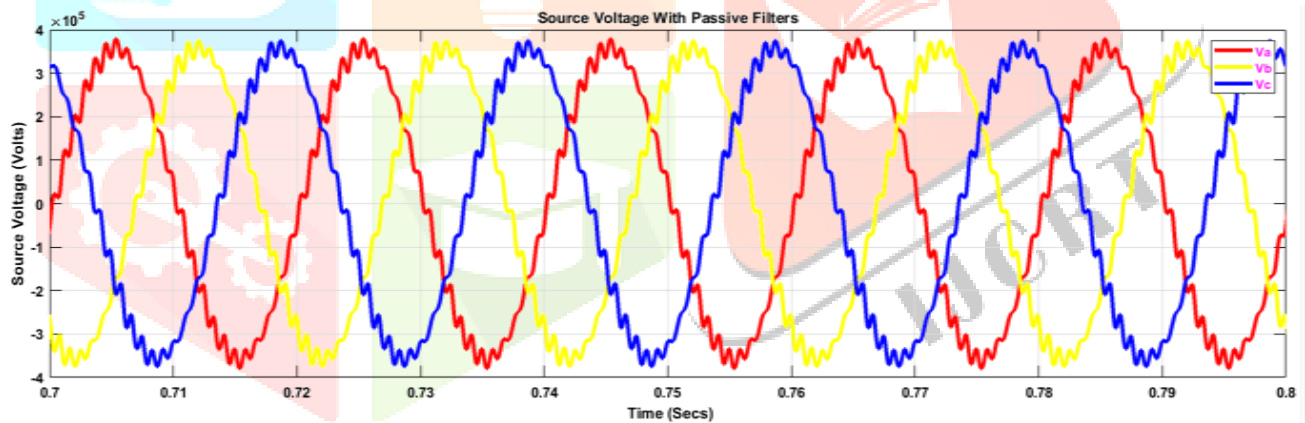


Figure 19 Source Voltage of Twelve Pulse Rectifier with 100 MVAR Passive Filters

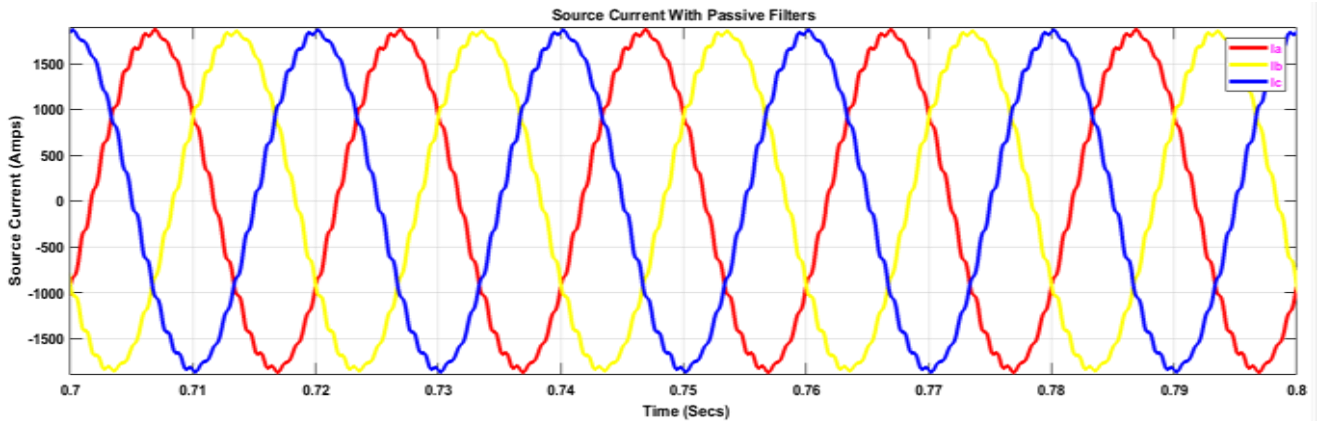


Figure 20 Source Current of Twelve Pulse Rectifier with 100 MVAR Passive Filters

Table. 3 Total Harmonic Distortions of Source Voltage and Source Current of Six Pulse Rectifier without and with passive filters.

Total Harmonic Distortion of Source Voltage and Source Current of Six Pulse Rectifier (in%)				
Signal	Without Filters	With 320 MVAR Filters	With 160 MVAR Filters	With 80 MVAR Filters
Va	12.60	1.98	3.73	6.03
Vb	12.59	1.98	3.73	6.03
Vc	12.59	1.98	3.72	6.03
Ia	16.24	1.32	2.56	3.99
Ib	16.24	1.32	2.56	3.99
Ic	16.21	1.32	2.56	3.99

Table. 4 Total Harmonic Distortions of Source Voltage and Source Current of Twelve Pulse Rectifier without and with passive filters.

Total Harmonic Distortion of Source Voltage and Source Current of Twelve Pulse Rectifier (in%)				
Signal	Without Filters	With 600 MVAR Filters	With 300 MVAR Filters	With 100 MVAR Filters
Va	11.91	0.58	1.75	6.17
Vb	11.91	0.58	1.75	6.17
Vc	11.91	0.58	1.75	6.17
Ia	9.16	0.57	1.36	2.69
Ib	9.16	0.57	1.36	2.69
Ic	9.16	0.57	1.36	2.69

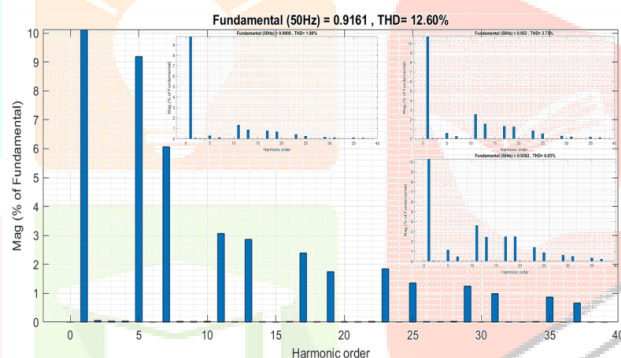


Figure 21 THD of Source Voltage of Six Pulse Rectifier without and with Passive Filters

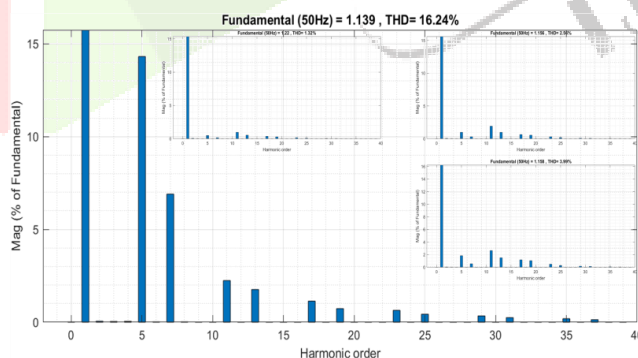


Figure 22 THD of Source Current of Six Pulse Rectifier without and with Passive Filters

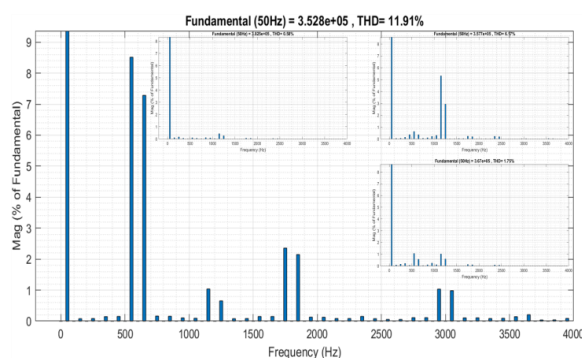


Figure 23 THD of Source Voltage of Twelve Pulse Rectifier without and with Passive Filters

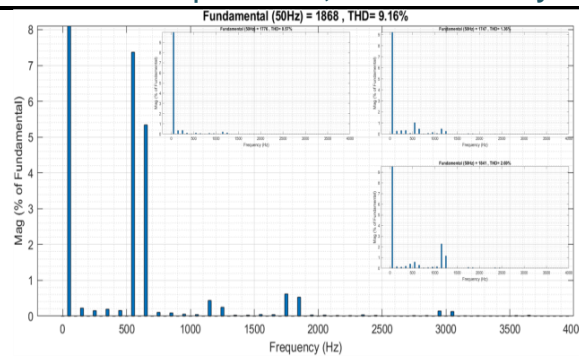


Figure 24 THD of Source Current of Twelve Pulse Rectifier without and with Passive Filters

V. RESULTS& DISCUSSIONS

a. SIX PULSE RECTIFIER:

Source Voltage and Source Current waveforms of Six Pulse Rectifier without passive filters was observed to be containing harmonics of 5th and 7th order, due to which these waveforms are not pure sinusoidal as shown in the Fig.5 and Fig.6 and the THD of these waveforms are 12.60% and 16.24% as shown in Fig. 21 and Fig. 22.

When 320 MVAR passive filter is connected to the Six Pulse Rectifier, the waveforms of Source Voltage and Source Current are almost sinusoidal as shown in Fig.7 & Fig.8, the THD of these waveforms are 1.98% and 1.32% as shown in Fig. 21 and Fig.22.

When 160 MVAR passive filter is connected to the Six Pulse Rectifier, the waveforms of Source Voltage and Source Current still contain harmonic content as shown in Fig.9 & Fig.10, the THD of these waveforms are 3.73% and 2.56% as shown in Fig. 21 and Fig.22.

When 80 MVAR passive filter is connected to the Six Pulse Rectifier, the waveforms of Source Voltage and Source Current were observed to be containing more harmonic content as shown in Fig.11 & Fig.12, the THD of these waveforms are 6.03% and 3.99% as shown in Fig. 21 and Fig.22.

b. TWELVE PULSE RECTIFIER:

The waveforms of Source Voltage and Source Current of Twelve Pulse Rectifier without passive filters are observed to be non sinusoidal due to dominant 11th and 13th harmonics as shown in Fig.13 and Fig.14 the THD of these waveforms is 11.91% and 9.16% as shown in Fig.23 and Fig.24.

By connecting a 600 MVAR Passive filter to Twelve Pulse Rectifier, the waveforms of the Source Voltage and Source Current were pure sinusoidal as shown in the Fig.15 and Fig.16 the THD of these waveforms is 0.58% and 0.57%. as shown in Fig.23 and Fig.24.

With a 300MVAR Passive Filter connected to Twelve Pulse Rectifier, the waveforms of Source Voltage and Source Current are not sinusoidal as they contain harmonics as shown in the Fig.17 and Fig.18; the THD of these waveforms is 1.75% and 1.36% as shown in Fig.23 and Fig.24.

By connecting a 100 MVAR Passive filter to Twelve Pulse Rectifier, the waveforms of the Source Voltage and Source Current were not sinusoidal as they contain more harmonic content as shown in the Fig.19 and Fig.20 the THD of these waveforms is 6.17% and 2.69%. as shown in Fig.23 and Fig.24.

VI. CONCLUSIONS

Six Pulse and Twelve Pulse Rectifiers used to convert three phase ac power to dc power behaves as non linear load to source thereby injecting harmonics into the system making the Source Voltage and Source Current non sinusoidal. So these rectifiers need filters to mitigate the harmonic produced by rectifiers.

In the proposed work, a passive filter of 320 MVAR when connected to Six Pulse Rectifier the harmonic content is almost nullified and Source Voltage and Source Current are pure sinusoidal. But when reactive power capacity of these filters is reduced below 320 MVAR, the harmonic content of these waveforms is increasing as required amount of reactive power is not compensated. For 80 MVAR passive filter, the harmonic content of Source Voltage is increasing. In order to mitigate and compensate the reactive power for six pulse rectifier with passive filter below 320 MVAR additional filters such as a Shunt Active Power Filter can be installed.

Furthermore, for Twelve Pulse Rectifier when a passive filter of 600 MVAR is connected the harmonic content is almost nullified and Source Voltage and Source Current are pure sinusoidal. But when reactive power capacity of these filters is reduced, the harmonic content of these waveforms is increasing as required amount of reactive power is not compensated. For 100 MVAR passive filter, the harmonic content of Source Voltage is increasing. A Shunt Active Power Filter can be installed to handle the harmonics and for reactive power compensation when passive filters were not able to compensate the reactive power as per the requirement.

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