JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Power Quality Improvement of Railway Traction using Passive Shunt Filter

[1]Ruma Sinha, [2]Vidya H.A, [3]Sudarshan Reddy H.R
[1]Global Academy of Technology, Karnataka, India,
[2]Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, India
[3]University B.D.T College of Engineering Davangere, Karnataka, India

Abstract: Electric railway traction system is a dynamically varying load with high rated power. In addition to this the usage of power electronic converters in this system causes power quality (PQ) issues such as harmonic distortion, voltage unbalance, voltage fluctuation etc. To mitigate this power quality problems many compensation strategies have been proposed in different literature; but they usually have high nominal rating and complex control algorithm. In this paper a passive shunt filter with a simple design is proposed to reduce the harmonics generated in traction power supply system.

***IndexTerms* - Electric traction, Passive filter, Power quality, THD.**

Introduction

Railway electrification has become popular due to multiple reasons such as reduced air pollution, heavy load transit ability, reduced carbon dioxide generation, higher efficiency etc. Railway traction uses AC or DC power supply with different voltage levels in different countries. In India, mainly 25 kV AC is used for mainline traction 750V DC is used in Bangalore and Kolkata Metro, Chennai, Mumbai and Delhi metro use 25kV AC through overhead catenary. The main factors negatively affect the traction power supply system performance are appreciable voltage drop at the end of long feeder section, current and voltage harmonics, overvoltage caused by resonant phenomena in the catenary network. Real time power quality parameters go beyond the permitted standards in the traction network, and in some cases in the utility supply system also gets affected. To obtain DC power supply, received three-phase AC is converted to DC using uncontrolled 6 pulse, 12 pulse or 24 pulse rectifiers at traction substation [1-3]. Depending on traction transformer's winding and the static converter used, the number of pulses is decided. Increased number of pulses reduces the harmonic component as well as ac ripple content, but it necessitates complex transformer winding scheme [4]. The obtained DC is supplied through the third rail which runs parallel to the two main lines in case of third rail system at specified voltage. In modern days, three-phase induction motors are preferred over DC motors as three-phase induction motors have multi-fold advantages over DC motors. Induction motors are robust, require very little maintenance, higher power to weight ratio, higher speed and more energy efficient. Structure of railway traction power system is shown in Figure 1.

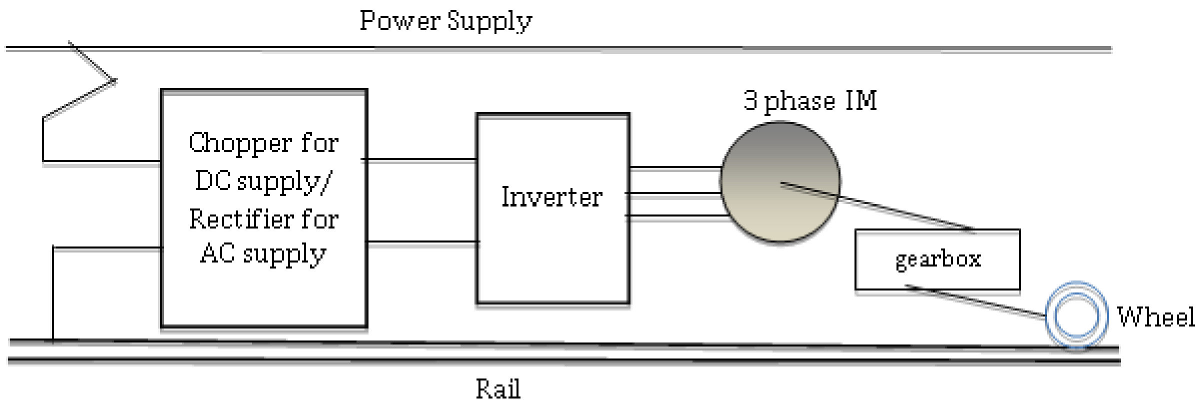


Figure 1: Structure of railway traction system

I. POWER QUALITY ISSUES

Traction loads have high power rating with dynamic and non-linear load characteristics. To supply the required power with proper control to the traction motor, the drive uses power electronics converters. A variable speed drive is required which may require frequent start and stop. Also, there is huge difference between peak load and the valley load.

The most important power quality issues in railway traction system are:

System Imbalance - System imbalance is one of the most serious issues with respect to the power quality of electric railway traction. Since most of traction load are single-phase load, it produces a negative sequence component (NSC) equal to the positive sequence component. The traction load is of heavy duty, so this large magnitude NSC harms the power system and must be attenuated.

Harmonics - Urban DC traction system uses 12 pulse rectifiers and generates large amount of harmonics (11th and 13th order) while AC traction system uses AC to DC to AC converters, which causes different order harmonics flowing into the three-phase power systems. Current and voltage harmonics generated creates a major power quality issue and must be compensated [5,6].

Reactive Power - Modern AC converters of traction motors use pulse width modulation techniques, which generate zero reactive power. In Traction Sub Station (TSS), Active and Reactive Power generation or transfer is required to compensate negative sequence component. Hence, compensation of reactive power is not taken care of separately.

Voltage Unbalance - Unbalanced current produces unbalanced voltages. As per IEC 6850 and EN 50163 in traction system, motor and other loads functions properly with 24% reduced magnitude and 10% increased magnitude. So, usually voltage unbalance is not considered as serious problem.

Power quality issues may cause malfunctioning of protective relays, instabilities, reduced lifetime, failure of equipment, decreased utilization factor etc. [7]. Hence, it becomes absolute necessity to improve the power quality of the traction system.

II. DESIGN OF PASSIVE FILTER TO COMPENSATE PQ ISSUES

Passive power filters consist of passive elements such as resistor, inductor, and capacitor. Some issues related to passive filters are it requires fixed compensation, change in temperature may cause little variation in parameters and filter functionality may degrade with aging. Active filters to compensate power quality issues involve complexity in design and has increased cost [8-10]. Thus due to low cost and simple design passive filters are used.

Single tuned filters are tuned to a specific frequency, with simple configuration and negligible losses. High pass filters are provided with damping resistors which reduces the quality factor. Low order high pass filter is realized using third order filter or C type filter. Double tuned filters are equivalent to two single tuned filters connected in parallel and can provide attenuation of two harmonics [11]. Quality factor (Q) is used to measure the effectiveness of filter performance depending on the sharpness of tuning frequency. The value of Q is expressed as the ratio of stored energy and energy loss per unit time. Also, Q is referred to as quality factor of reactance for the prescribed tuning frequency given by equation 1.

$$Q = \left(\frac{nX_L}{R}\right) \qquad (1)$$

Filter configuration is shown in figure 2 and the filter parameters can be calculated from equation [2 – 6].

$$C = \frac{Q}{V^2 \times 2\pi f} \qquad (2)$$

$$L = \frac{1}{(2\pi f_r)^2 C} \qquad (3)$$

$$C_H = \frac{Q}{V^2 \times 2\pi f} \qquad (4)$$

$$L_H = \frac{1}{(2\pi f_2)^2 C_H} \quad (5)$$

$$C_L = \frac{1}{(2\pi f_1)^2 L_L} \quad (6)$$

Where Q = Reactive power to be generated by the filter, V = Voltage levels at which filters are to be installed, f = fundamental frequency, f_1 = first tuning frequency, f_2 = second tuning frequency.

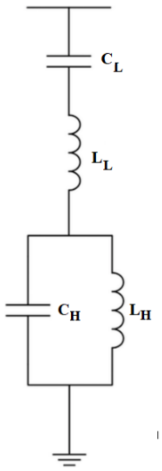


Figure 2: Double tuned filter

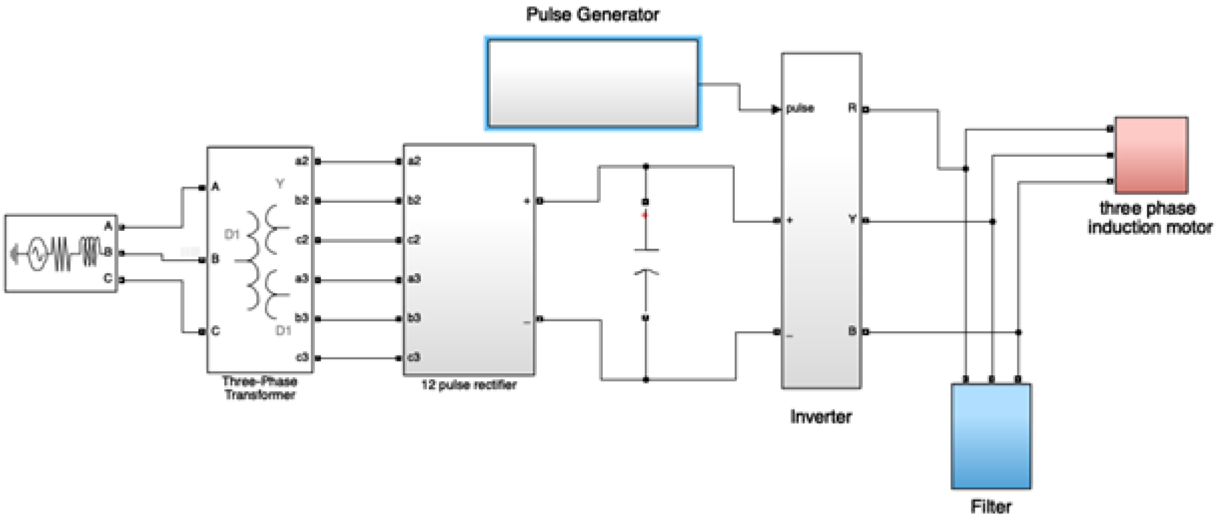


Figure 3: Overall Block Diagram

IV. SIMULATION RESULTS AND DISCUSSION

This work focuses on a 750V DC third rail using a three-phase induction motor as drive. In traction substation 11 kV three-phase AC is received. Three-phase three winding Y – Y - Δ step down transformer is used with a 12-pulse converter to obtain 750V DC voltage link. Overall block diagram of the system is shown in figure 3. Three-phase induction motors are used as traction motor. Auxiliary load also is connected in addition to two three-phase induction motors as traction load. PWM inverters are used to convert the voltage of the DC link to three-phase, which is fed to the induction motors. A model has been developed using MATLAB Simulink depicted in Figure 4. Since the traction load requires different level of speeds the torque requirement also varies. A variation in torque requirement of induction motor is created for the simulation study as shown in figure 5. Simulation study has been carried out under different stages:

A. Without filter

B. With passive filter connected in load side

C. With passive filter connected in source side

D. With passive filter connected in both source side and load side

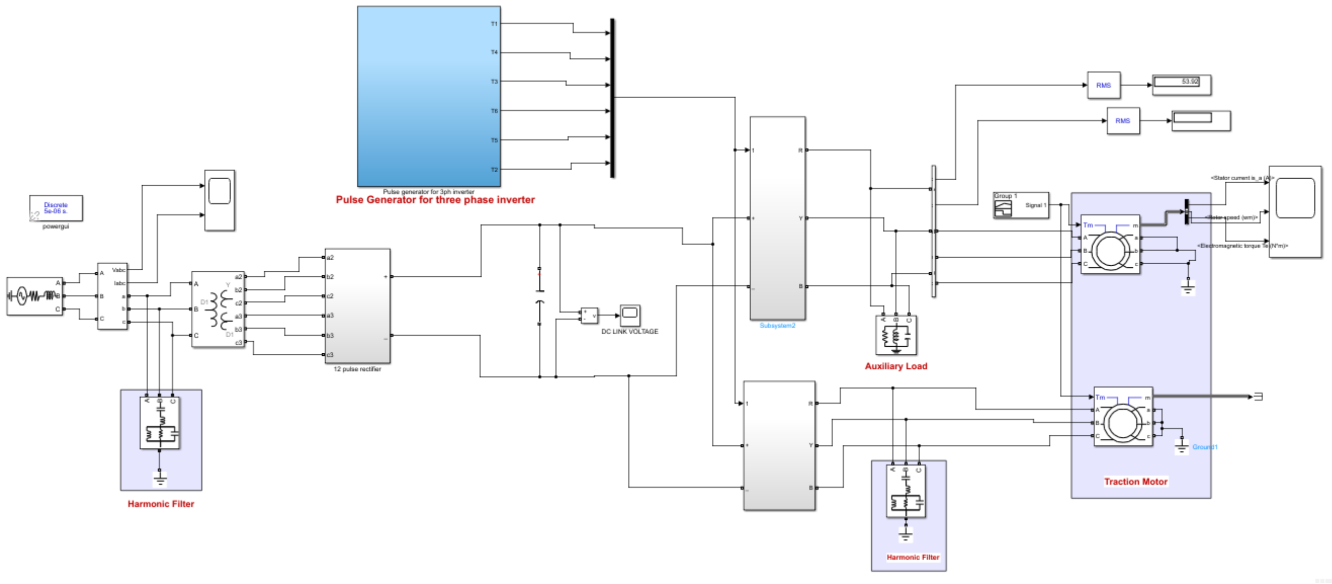


Figure 4: Simulink model of the overall system

Figure 6 shows the stator current, rotor speed and electromagnetic torque of induction motor used as traction load. The electromagnetic torque output of induction motor follows the torque requirement given as input. It can be observed that stator current increases as the torque increases, while rotor speed reduces with the increase in torque.

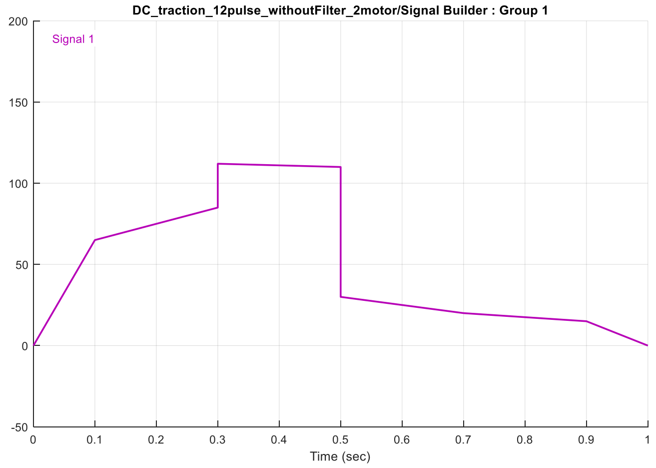


Figure 5: Variation in torque requirement of traction load

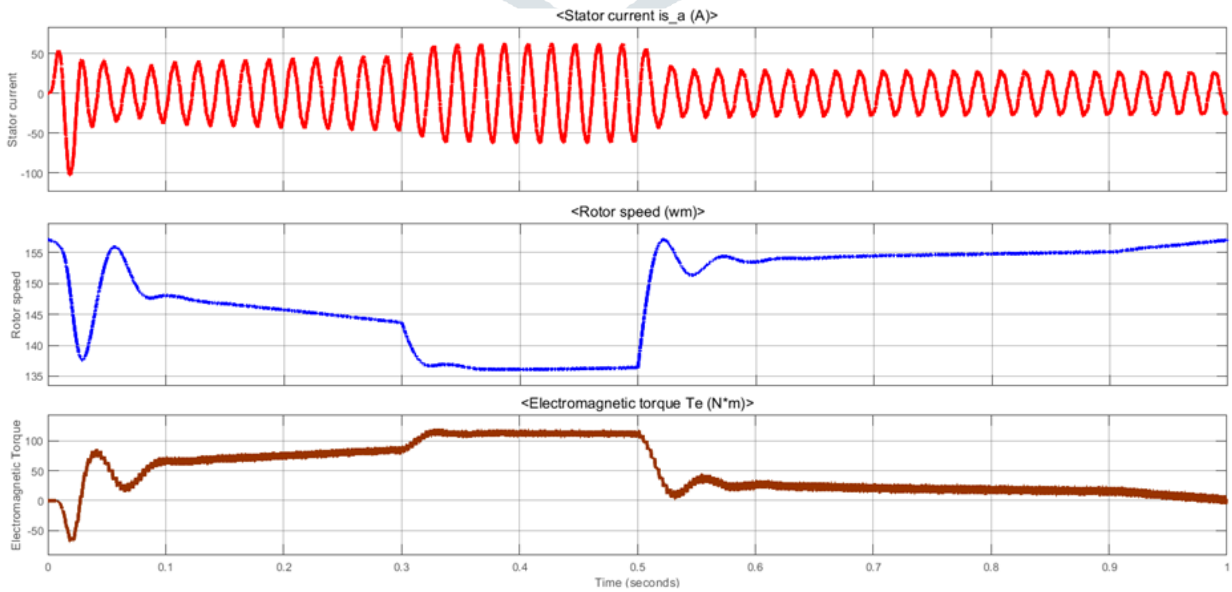


Figure 6: stator current, rotor speed and electromagnetic torque

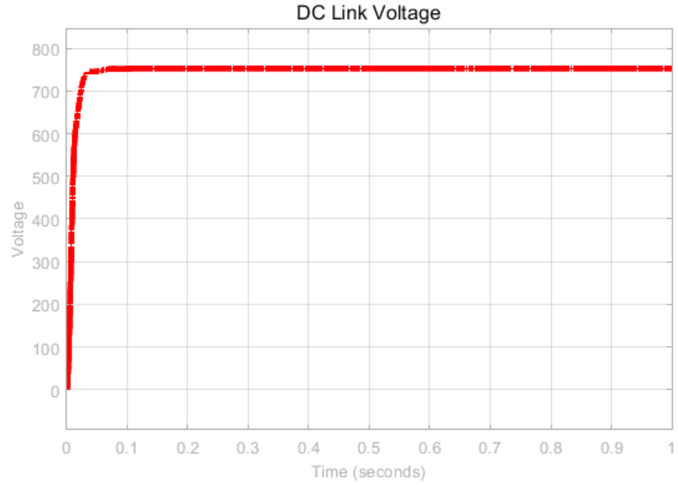
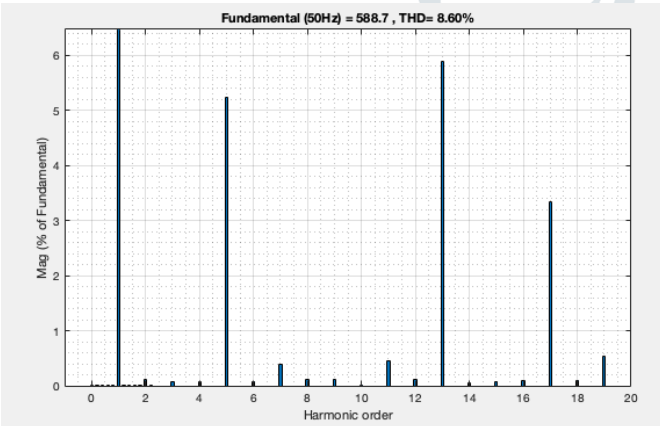
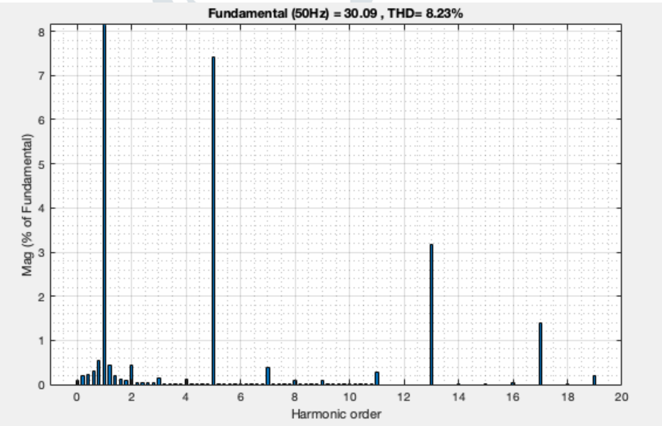


Figure 7: Voltage of DC link without filter

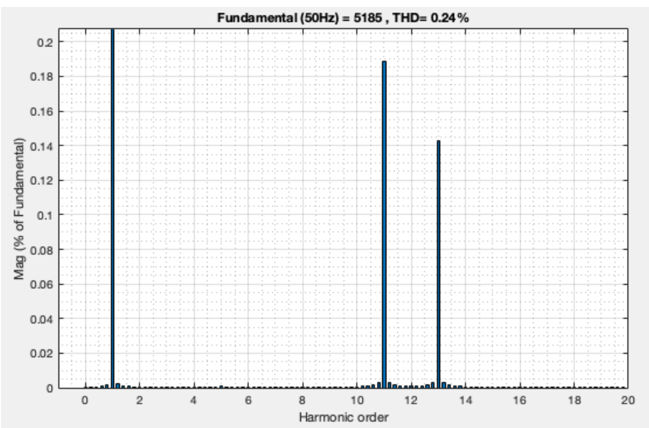
The DC link voltage is maintained at 750 V which refers to the third rail voltage. This voltage for the system without filter is shown in figure 7. FFT analysis was carried out to find THD in source side and load side current and voltages. It was observed that the current drawn from the supply contains a THD of 33.93%. The result is tabulated in table 1. FFT analysis is also illustrated in figure 8. It is observed that load side voltage and current has higher magnitude of 5th and 13th harmonics present.



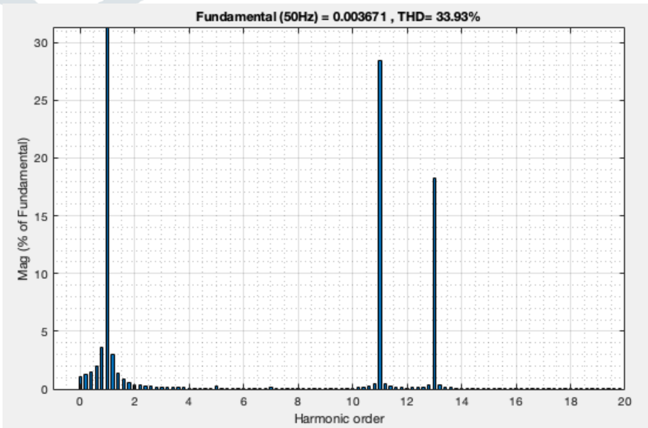
a) output voltage



b) output current



c) input voltage



d) input current

Figure 8: THD analysis of input voltage without filter

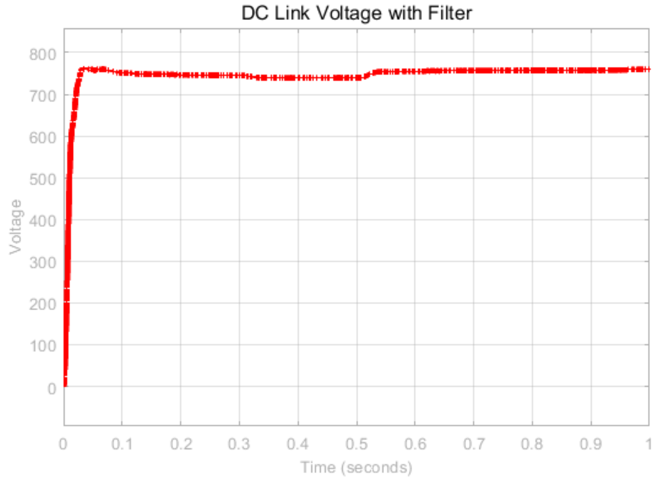
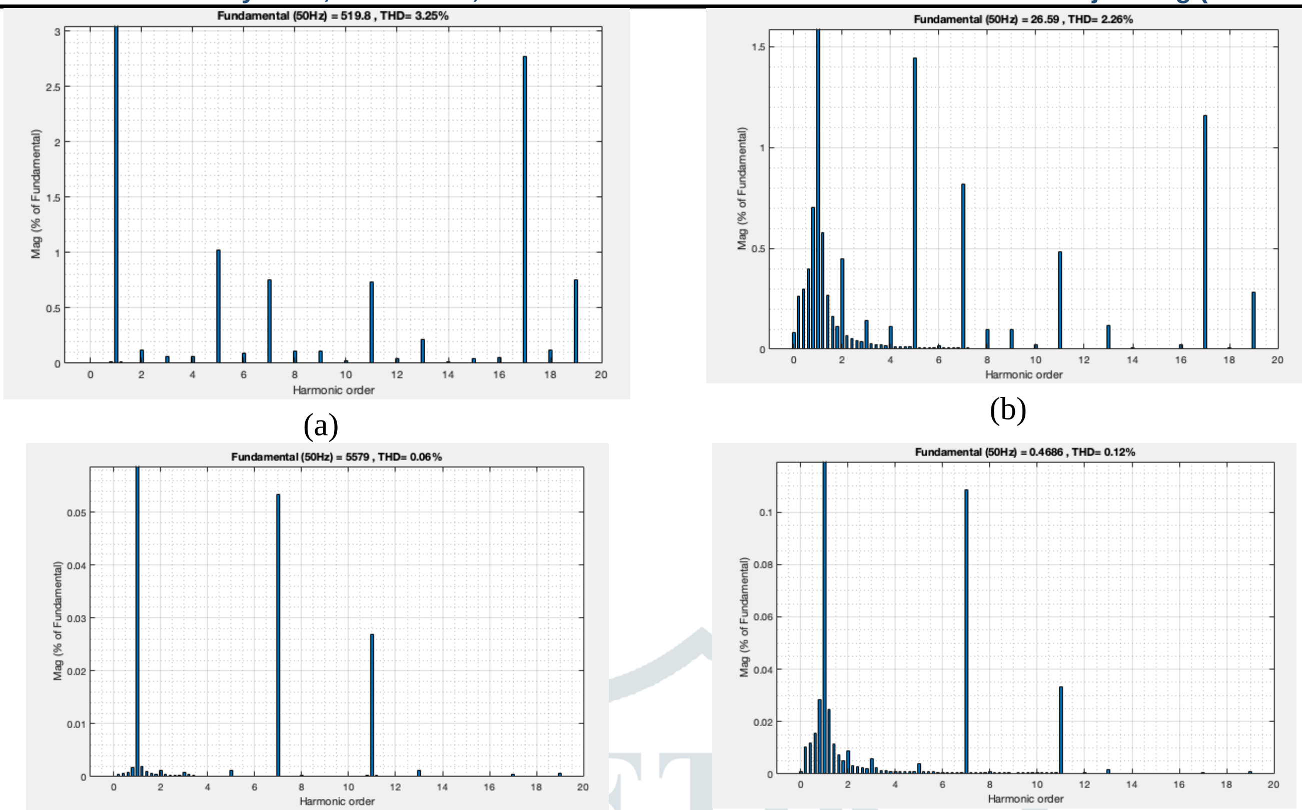


Figure 9: Voltage of DC link with filter connected in both source and load side

Table I: THD Analysis without and with filter

Location of filter	Type of Filter	Parameters	THD in load voltage	THD in load current	THD in input voltage	THD in input current
--	Without filter	--	8.6%	8.23%	0.24%	33.93%
Load side	With single tuned filter	fr = 5x50 Hz	6.85%	3.93%	0.39%	10.36%
		fr = 13x50 Hz	5.39%	7.29%	0.44%	8.29%
	With double tuned filter	fr_1=5x50Hz fr_2=13x50 Hz	3.25%	2.29%	0.44%	8.46%
Source side	With single tuned filter	fr = 5x50 Hz	8.6%	8.23%	0.07%	0.08%
		fr = 13x50 Hz	8.6%	8.23%	0.01%	0.03%
	With double tuned filter	fr_1=5x50Hz fr_2=13x50 Hz	8.6%	8.23%	0.01%	0.03%
Both source side and load side	With single tuned filter	fr = 5x50 Hz	6.85%	3.92%	0.13%	0.16%
		fr = 13x50 Hz	5.39%	7.29%	0.02%	0.06%
	With double tuned filter	fr_1=5x50Hz fr_2=13x50 Hz	3.25%	2.26%	0.05%	0.12%

Passive filter designed to eliminate 5th and 13th harmonic is connected at the load side. The result as shown in table 1 shows that load side voltage and current THD can be reduced, however the source side current THD is not improved. Then the filter is connected at the source side and it was observed that THD in the current drawn from the supply is reduced, keeping load voltage and current THD unaffected. Then the filter is connected at both source side as well as load side. This helps in improving the THD in both load side and source side voltage and current. Both single tuned and double tuned filter are used, and result is compared. The DC link voltage with the filter is shown in figure 9. It was observed that the voltage is maintained at 750 V with minor fluctuation. THD analysis of source side and load side voltage and current with filter connected in both source and load side are shown in figure 10.



(a) (b)

(c) (d)

Figure 10: THD analysis with filter connected in both source and load side a) output voltage b) output current c) input voltage d) input current

V. CONCLUSION

A traction system with 750 V DC third rail has been simulated using MATLAB-SIMULINK. The THD analysis is carried out for the system and it is observed that system introduces harmonic distortion to the system. To improve the system performance passive filter is designed and connected under different conditions such as three-phase harmonic filter connected at load side, filter connected at source side and filters connected both at load and source side. It has been seen that when the filter is connected in the source side the THD at input side current and voltage is within 1% while it does not affect the load side voltage and current THD. When the filter is connected at load side, the THD in load side as well as input side current and voltage are reduced. But source side current THD still remains more than 5%. With the filters connected in both the sides input side as well as load side voltage and current THDs are within the limit as prescribed by IEEE-519-1992 and IEC-61000. However, the input side filter connection causes a voltage swell whereas load side filter connection causes a voltage sag.

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