Harmonic distortion from induction furnace loads in a steel production plant

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Abstract

The use of induction furnaces for steelmaking has grown dramatically in the last decade throughout the world. The steel melting process involves the use of large quantities of energy in a short time and in some instances the process causes large decrease in the quality of electric power system to electricity users on the same network. In this paper, a new block for induction furnace was developed using MatLab Simulink software and the effect of induction furnace loads on the steel plant supply network was analyzed in terms of total harmonic distortions of voltage and current, using the developed block. Installation of a commensurate passive filter for distortion reduction was proposed, designed and simulated. The simulation of the installation of the designed passive filter shows that the filter reduced the distortions by approximately 60%, limiting the residual distortions to permissible values. The new block provided proved to be effective in harmonic distortion analysis in the power supply system of a steel production plant and can be applied for similar studies.

Keywords: harmonics distortion, Induction furnace, passive filter, simulation and total harmonic distortion (THD), Nigeria.

1. Introduction

A new generation of industrial induction melting furnaces was developed during the last 25 years. The development of flexible, constant power tracking, medium-frequency induction power supplies has resulted in the widespread use of the batch melting methods in modern foundries [3]. An induction furnace is an electrically run furnace used for melting metals. It produces heat by the use of an alternating current solenoid coil, a process otherwise known as electromagnetic induction [6].

The new generation of induction melting furnaces has brought about the most economic ways of producing steel. The problem with this kind of furnaces is the creation of a considerable harmonic distortion. The cause of the distortion is within the induction furnace design and operation. The induction furnace draws current which is non-sinusoidal in nature because of the rectification/inversion phenomena of their operation from a sinusoidal source which leads to a distorted current waveform. Non-sinusoidal/distorted current occur as a result of the presence of harmonic contents in the current waveform drawn by these induction furnace. Since induction furnace loads are nonlinear, the harmonic currents generated by the loads will cause a voltage drop across source impedance which causes decrease in power quality [2]. If these distortions exceeds the recommended limit it can cause over voltage and excessive currents, overloading of power factor correction, increased error in energy meters, mal functioning of protective gears such as relays and circuit breakers, tripping of machines at smaller loads and inductive interference with neighboring communication network [4]. The distortion created by the medium-voltage induction furnace affects the voltage supplied by the feeding distribution network, which in turn could disturb other users supplied from the same network. Therefore, it is necessary to have corrective actions in order to fulfill the regulation concerning voltage harmonic distortion (VTHD) and current harmonic distortion (CTHD): VTHD<=7% and CTHD<=5% [7]. In order to mitigate expected VTHD and CTHD conditions, passive filters are proposed and designed. Theoretically, the filters can overcome the resonance problems associated with the power factor correction capacitors. In addition, the filter can work as a dynamic compensator of reactive power, depending on the instantaneous needs of reactive power of the steel plant.

Before designing any corrective action, it is necessary to assess the expected distortion introduced by the studied installation into the distribution network. In this study, simulation is applied, which allows safe measuring of the harmonic distortion created by a system before and after any corrective action is introduced. Therefore, the motive and aim of the study is to determine and analyse expected VTHD and CTHD on introduction of specific steel plants in a typical distribution system configuration of the Nigerian environment, which will assist decision making in present system operation and planning of effective service delivery especially in terms of quality.

2.Research Methodology

2.1 Simulink Model of Induction Furnace

Induction furnaces are classified based on their operating frequency. High frequency induction furnace ranges from 1000Hz and above, medium frequency is from 400Hz to 800Hz and low frequency ranges from 400Hz and below. In this study, a medium frequency induction furnace was modelled in MatLab Simulink using Simulink blocks contained in the SymPowerSystems block set. As there is no induction furnace model in Simulink, new blocks were developed for the induction furnace used.

The furnace circuit, as shown in figure 3, is fed from a 3.6 MVA-11/0.66/0.66kV three winding transformer. The secondary winding feeds a thyristor controlled rectifier and the tertiary feeds another identical rectifier. The rectification has a 12-pulse configuration. Both rectifiers are connected in series including filtering coils that improve the direct current obtained. The direct voltage outputs of the rectifiers were coupled and connected to a medium frequency inverter to generate a 500 Hz one-phase alternating current of controllable amplitude. The output of the inverter is connected in series with induction coil. A capacitor bank is connected in parallel with the induction furnace coil to achieve a controllable resonance of the coil. The voltage at the coils that melt the steel is 1200V (500 Hz), and the approximate energy consumption rate of the coil is 3000 kW. The induction furnaces work in the resonant frequency with the capacitor banks connected in parallel. The coils have no core, as it is the scrap which takes its place. The resonant frequency value varies with the condition of the scrap as the self-inductance of the coil changes. Therefore this frequency value is controlled by the inverter control system so that capacitors and coil are always in resonance. When the furnace starts working the frequency is low (400 Hz) and its values increases as the scrap is melted.

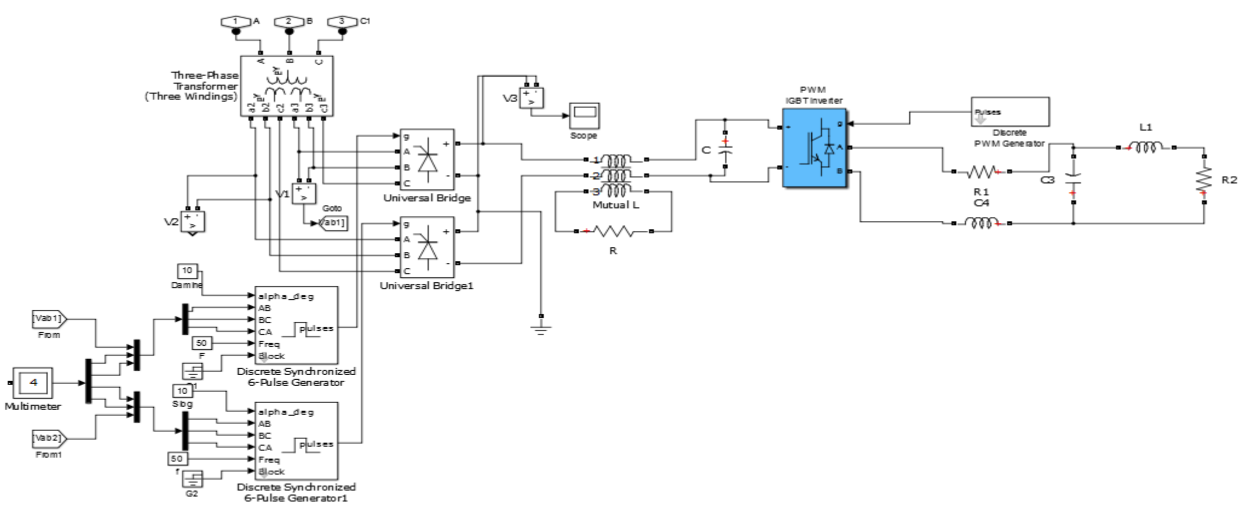

Figure 3. Model of Induction Furnace.

2.2 Modelling of the Steel Production Plant

In this paper, the steel plant setup comprises of two induction furnaces, continuous casting, finishing mill and the general services as shown in figure 4. All the elements were modeled using existing Simulink blocks contained in the SymPower Systems blockset. The distribution transformers of the general services and the finishing mill consume 2000 kW each with a cosφ of 0.85. For simulation purposes they have been modeled as a linear load of these characteristics. This is acceptable as their consumption is only a little portion of the total power consumed in the plant and they do not produce any distortion.

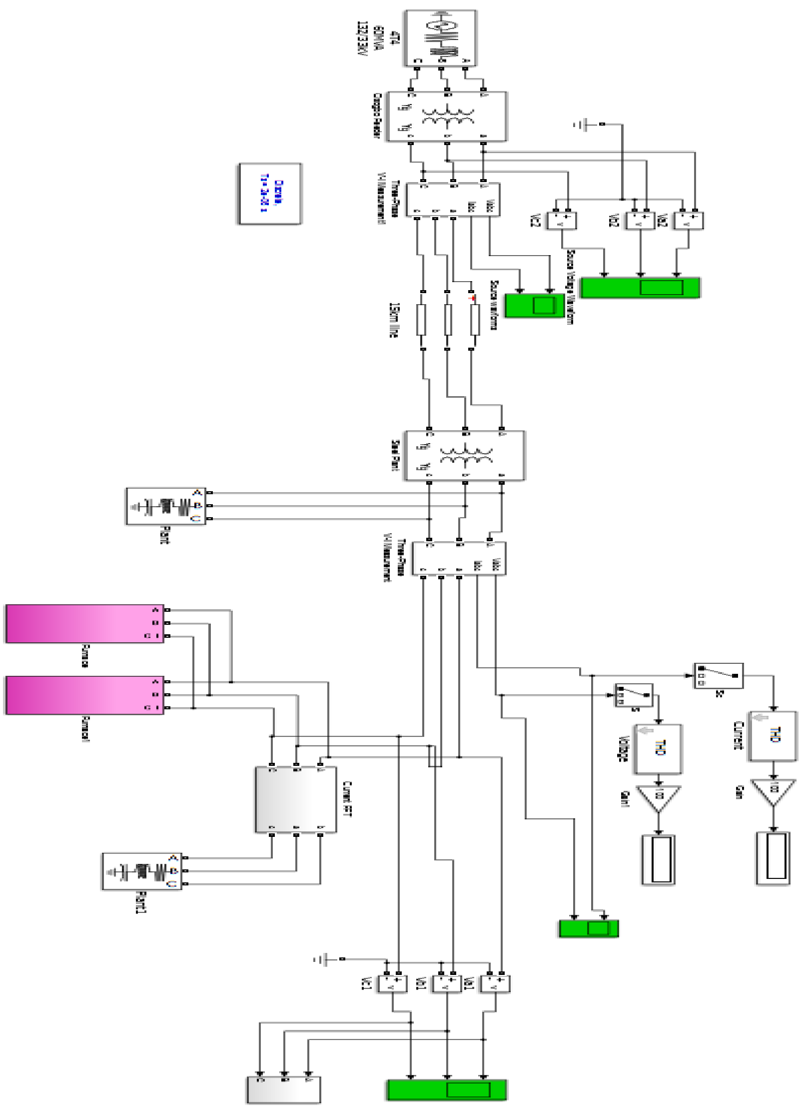

Figure 4. Model of Steel Production Plant.

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2.3 Modelling of Passive Filter

In this study, passive filters were modeled using available inductance, capacitance, and resistance elements in the Simulink block, configured and tuned to control harmonics. The designed Passive filter (figure 5) was placed closer to harmonic generators (non-linear loads) to filter more efficiently and are tuned slightly lower than the harmonic frequency for safety.

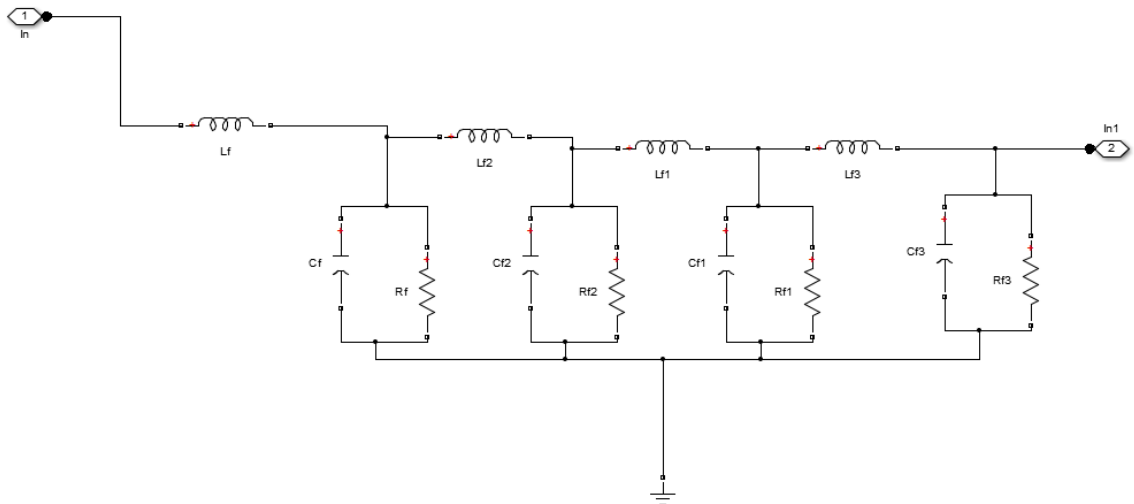

Figure 5. Model of Passive Filter.

The filter was inserted in parallel with the induction furnace loads and it was located in the point of common coupling with the distribution network, as shown in figure 6. In this section the simulation analysis of the filter was described for Induction Furnace loads and the FFT analysis has been carried out simultaneously. A Simulink block was developed to perform the harmonic analysis of the voltage and current signals present in the network.

The design parameters for each filter were evaluated as in equation 1:

$$Q_c^{req} = Q_c^{r0.85r} - Q_c^{r0.95r};\ Q_c^n = \frac{Q_c^{req}}{4};\ X_c^n = \frac{U^2}{Q_c^n};\ X_l^n = \frac{X_c^n}{n^2};\ L^n = \frac{X_l^n}{2\pi f_n};\ C^n = \frac{1}{2\pi f_n X_c^n};\ R^n = \frac{nX_l^n}{q}, 0.5 < q < 5;\ q = 3 \quad (1)$$

where R^n, L^n, C^n, f_n, X_L^n, X_c^n are active resistance, inductance, capacitance, cut-off frequency, inductive reactance, and capacitive reactance per filter for n[th] harmonic respectively; q is quality factor; Q_c^{req} is total required compensation of reactive power of the steel plant, Q_c^n is reactive power capacity per filter; $Q_c^{r0.85r}$, $Q_c^{r0.95r}$ are reactive loads of steel plant at power factors of 0.85 (existing) and 0.95 (desired) respectively.

Table 1 shows the parametric values of the passive filters designed in mitigating the effect of harmonic disturbance on the network as shown in figure 5.

Table 1: Parameters of Passive Filters.

S/N	Filters	PARAMETERS												
		Given					Computed							
		N	f_n (Hz)	q	$Q_c^{(0.85)}$	$Q_c^{(0.95)}$	Q_c^{req}	Q_c^n	X_c^n	X_l^n	C^n (μf)	$L^n (\Omega)$	$R^n (\Omega)$
1	3rd Filter	3	100	3	1.86	0.985	0.873	0.25	554	61.56	2.87	0.098	92.34
2	5th Filter	5	200	3	1.86	0.985	0.873	0.228	554	22.16	1.43	0.018	55.4
3	7th Filter	7	300	3	1.86	0.985	0.873	0.223	554	11.3	95.8	6	39.57
4	9th Filter	9	400	3	1.86	0.985	0.873	0.22	554	6.84	71.8	2.72	30.78

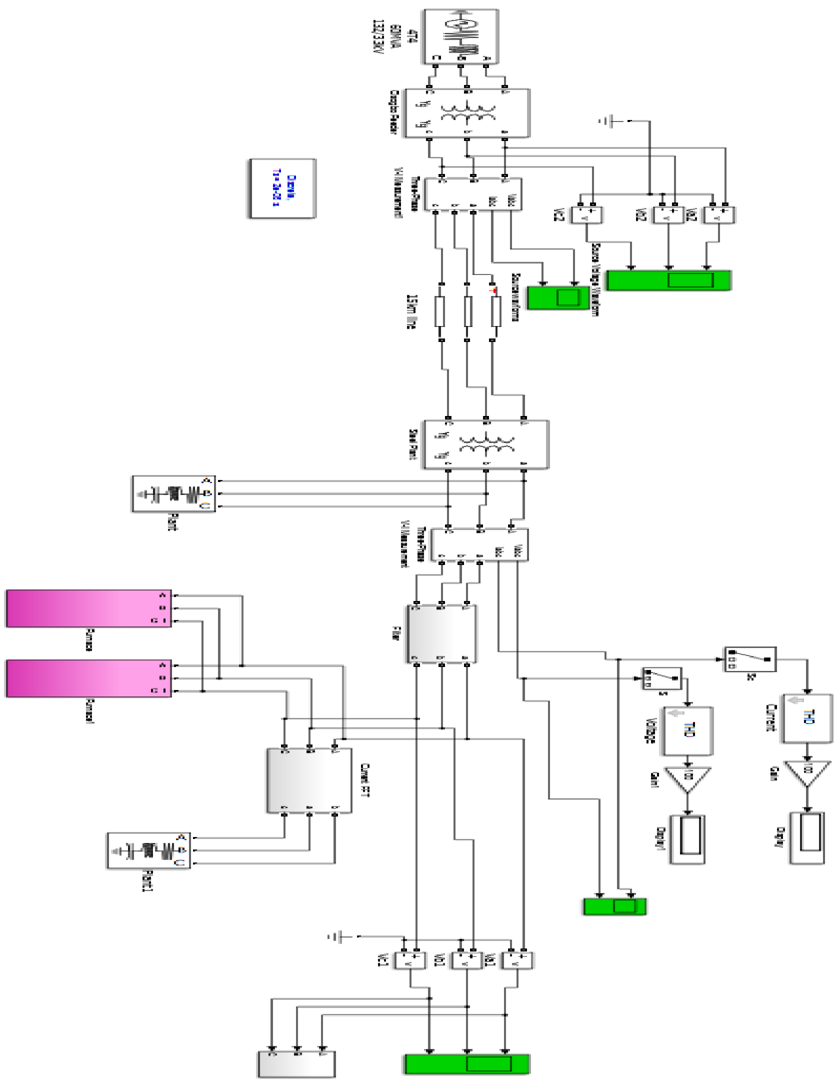

Figure 6. Model of the Steel Plant with the filter.

3 Results and Discussion

In this study, a steel plant was simulated considering the induction furnaces load. The VTHD created by the plant load was measured and after the passive filter has been added, the distortion was measured again as shown in the figure 7:

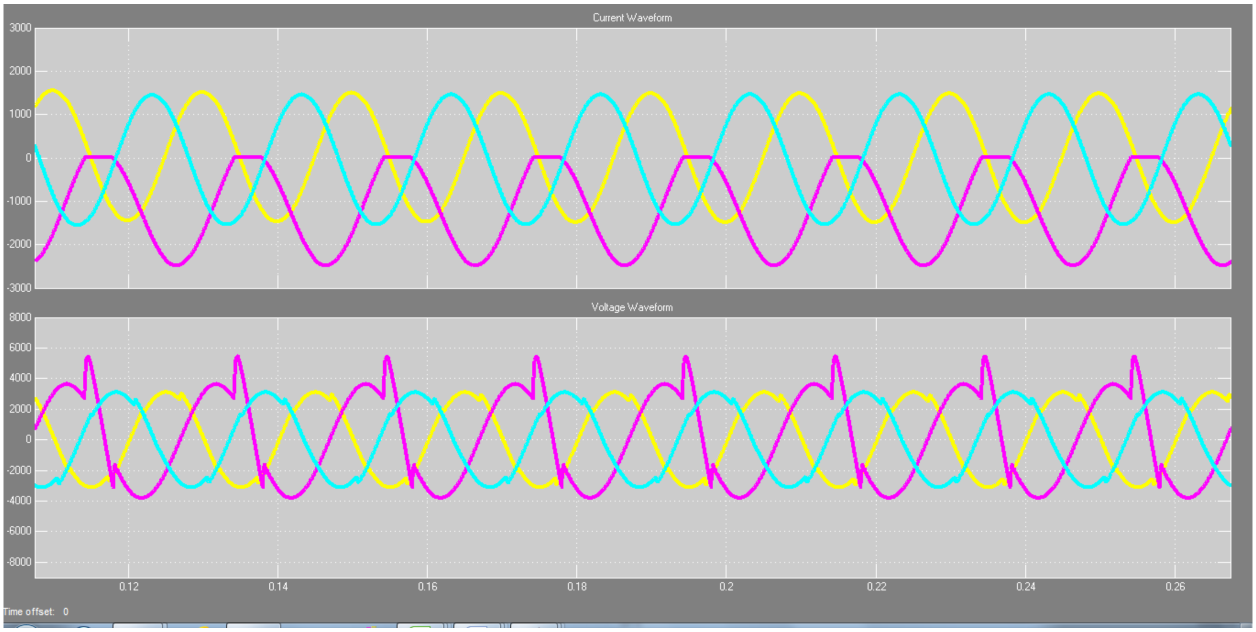

Figure 7: Waveforms of current and voltage at the steel plant (VTHD=24.91%; CTHD=17.47%).

Figure 7 shows the distorted current and voltage waveforms at the steel plant. The CTHD value is 17.47% while the VTHD is 24.91%; voltage has more distortion than current; and both values exceed their respective standard maximum limits, and should be mitigated as this is unhealthy for the other system loads.

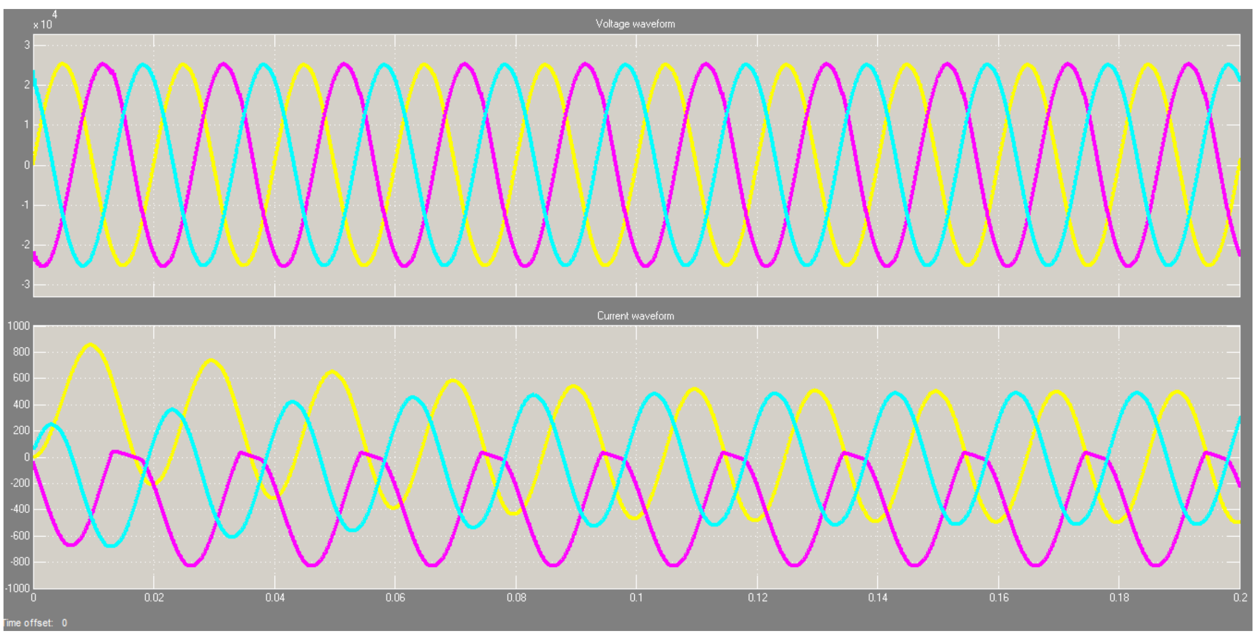

Figure 8. Waveforms of voltage and current at the supply.

The waveform distortions of voltage and current at the supply source are shown in Figures 8. The results here shows that current waveform is more distorted than voltage waveform, while in the case of the steel plant the voltage is more distorted than current.

When the passive filter were applied the distortion was reduced as shown by the waveforms in figures 11 and 12. The CTHD of the current was reduced from 17.47% to 7.44% and the VTHD from 24.91% to 10.06%.

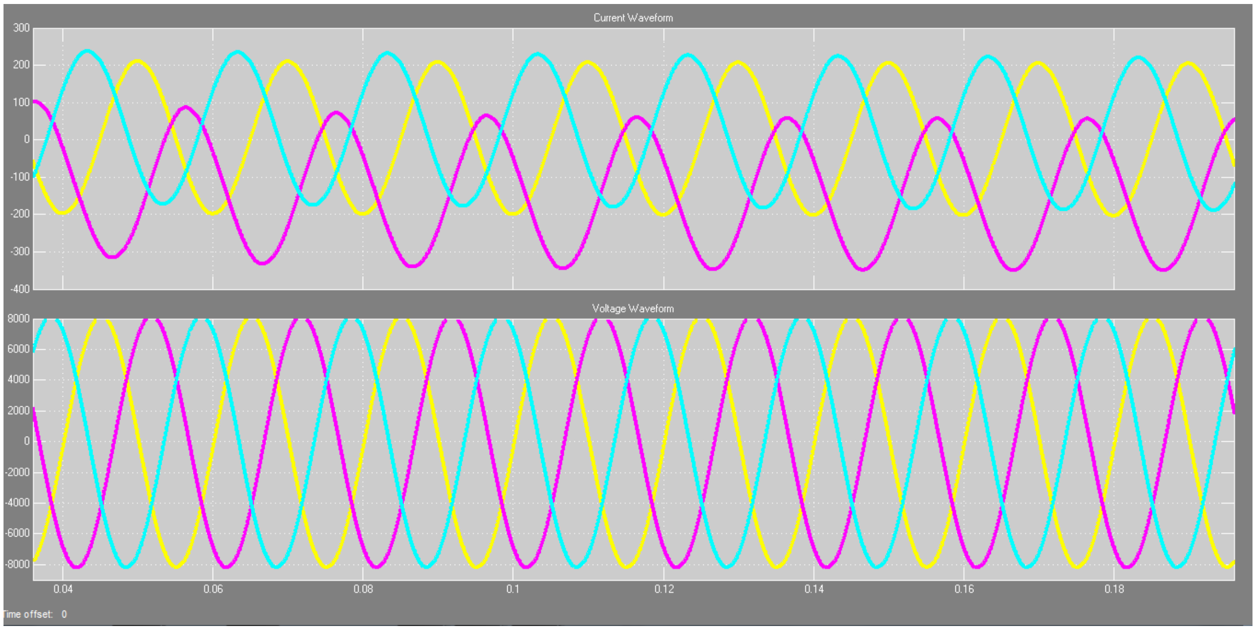

Figure 10: Waveforms of current and voltage at the steel plant with Passive filter (VTHD=10.06%; CTHD=7.44%)

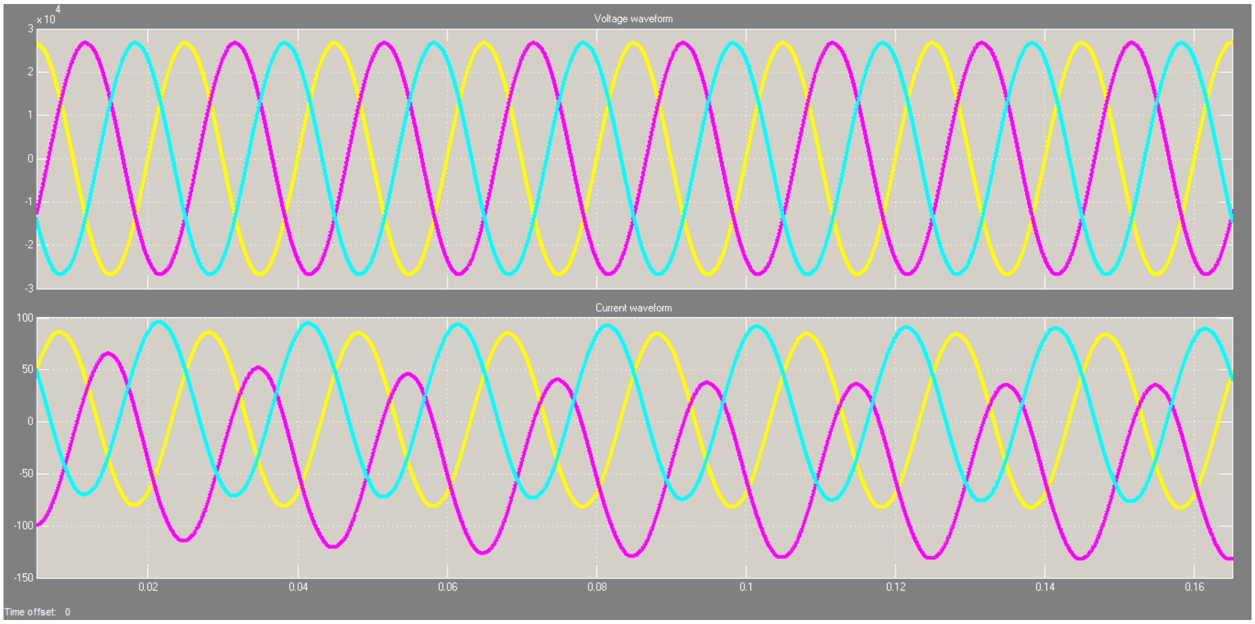

Figure 11. Waveforms of Voltage and Current at the supply with Passive Filter.

4.Conclusion and Recommendation

The new block developed proved to be effective in harmonic distortion analysis in a steel plant as carried out in this paper. Here the total harmonic distortion (THD) was measured by the THD block in Simulink. The distortion for both voltage and current due to the steel plant were excessive and could be mitigated using filter of commensurable design as herein proposed. Due to the estimated level of distortions in power supply network, it is certain that other loads supplied from the same network will be affected. Moreover, the reduction of the distortion by passive filter was simulated and effective in mitigating distortion to below tolerance limit. The simulation of the installation of the designed passive filter shows that the filter reduced the distortions by approximately 60%, limiting the residual distortions to permissible values.

Furthermore, power distribution companies, especially in the Nigerian condition, should consider as mandatory the introduction of power filters into the supply network where a steel plant installation exists or is proposed in order to mitigate the adverse effects of the generated harmonic distortion on the other load categories such as the adjoining township distribution network loads.

References

[1] Anne Ko, Wunna Swe, and Aung Zeya (2011): Analysis of Harmonic Distortion in Non-linear Loads- The First International Conference on Interdisciplinary Research and Development Thailand.

[2] David Chapman (2001): Power Quality Application Guide: Harmonics Causes and Effects, Copper Development Association, UK.

[3] Gandhewar V. R, S. V. Bansod, and A. B.Borade (2011): Induction Furnace - A Review. International Journal of Engineering and Technology Vol.3 (4), pp 277-284.

[4] Kusko. A and Thompson. M. (2007)**:** Power Quality in Electrical Systems, The McGraw-Hill Companies, U.S.A

[5] Rundev. V (2002): Handbook of Induction Heating, Technology and Engineering Journal, U.S.A.

[6] Swapnil Arya and Bhavesh Bhalja (2011): Stimulation of steel melting furnace in MATLAB and its effect on power quality problems, National Conference on Recent Trends in Engineering and Technology, Nagar, Gujarat, India.

[7] J. Arrillaga, D. A. Bradley, and P. S. Bodger (1985): Power System Harmonic, John Wiley &Sons, New York.

[8] Surya Santoso (2007): Power Quality Requirements for Reliability- Towards Perfect Power Quality, University of Texas, Austin**.**