Simulation of the Application-based Design on the Harmonic Analysis and ontrol in Bar Plant

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***Abstract*—Purpose: with the development of the metallurgical industry, the influence of the metallurgical enterprise on power quality is more and more serious, and the harmonic content of metallurgical equipment is much more than the allowable value of the harmonic content. In this paper, the composition and content of harmonic in the power supply environment of bar mill are analyzed, a passive filter with good effect and low cost is designed.**
Design/methodology/approach: in this paper, the specific settings of the parameters of the passive filter device, the bar plant in the typical harmonic processing, and the use of MATLAB/SIMULINK software simulation to achieve.
Findings and Originality/value: the three times, five times and seven times of the bar mill were designed, and the passive filter was used to filter the filter. The simulation results were good and the results were correct.
Research limitations/implications: in the study of the typical harmonic in the bar plant, we should also take into account the higher order integer harmonics and various inter harmonics, in order to make the results more accurate.
Practical implications: the passive filter is low cost, safe and reliable operation, it is the first choice for ensuring the power quality in bar mill.
Originality/value: the study of power quality has important theoretical value and practical significance. In this paper, the parameters of each link of the passive filter are given in detail. After the simulation, it is proved that the power quality of the bar mill can be improved.

Index Terms*—*Bar Plant, harmonic, passive filter, simulation

I INTRODUCTION

A. Production Process And Supply In Bar Plant

The electric arc furnaces in the metallurgical enterprises, as well as furnaces and rolling mills, due to their very large capacities, often bring out the impact of a large load, from which the harmonic generation becomes the most serious environmental pollution in power supply. To a larger extent, this may adversely affect the quality of power supply and the normal function of these electrical equipment, and furthermore, the security and stability of the entire power system operation.

Normally, a bar plant follows such a production process: continuous casting billets required for the rolling process are transported through hot rollers from the continuous casting plant into the billet workshop. The process is shown in Fig. 1. This process includes the production of both hot billets and cold billets. In the hot billet production, pre-heating the billet is needed, whereas in the cold billet production, the billets are directly fed into the furnace through rollers. For the bar processing, the bar plant mainly involves the use of furnaces, rolling mills and other equipment, where furnaces and rolling mills are each powered by a special branch to ensure that power supply is stabile. Fig. 2 is the schematic diagram of its power supply.

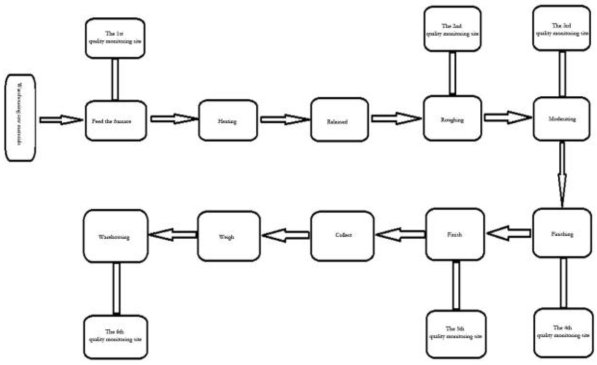


Figure 1 - Diagram of the Process Flow of Bar Plant

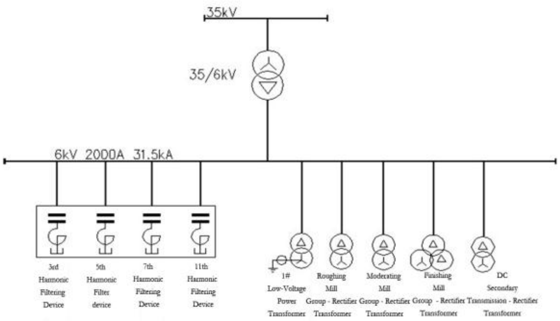


Figure 2 - Main Wiring Diagram for Power Supply of Bar plant

B. Harmonic Generation Of Bar Plant

Currently, many countries have respectively developed their own standards for the limits to harmonic current and voltage according to the characteristics of power supply. For the harmonic currents and voltages, China also issued the corresponding standards --GB/T 14595-1993 "Power Quality: Harmonics with Utility Grid." This standard specifies the content criteria of harmonic voltage in public distribution system and the allowed current injection into the common connection points under different voltage levels. According to experimental test data collected from various bar plants, the harmonic currents presented the components and contents as shown in Table 1.

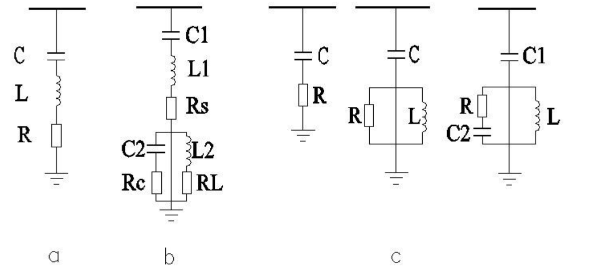
Table I
Main Harmonic Current Content

Harmonic Times (Frequency)	Harmonic Current Size (A)	Harmonic Content (%)	Allowed values (A)	Excessive or not?
Fundamentals (50Hz)	2000	-	-	-
3 times (150Hz)	56. 06	2. 80	34	Excessive
5 times (250Hz)	65. 72	3. 29	34	Excessive
7 times (350Hz)	23. 39	1. 17	14	Excessive
11 times (550Hz)	19. 12	0. 96	16	Excessive

The analysis results revealed that the power supply system in the rod mill, at the 3rd, 5th, 7th and 11th times, had its harmonic current content that exceeded the standard value specified. Meanwhile, the voltage had a total harmonic distortion rate THD_U of 5.44 percent, 4 percent more than the allowable value, hence the need for harmonic control to meet the requirements.

II. Passive Filter

Passive filters, also known as AC filter or LC filter by setting, and parameters C of L to R, are responsible for filtering out the different harmonics. The topologies of common LC filters are shown in Fig. 3.



a. Single Harmonized Filter b. Double Harmonized Filter c. High-Pass Filter
Figure 3 Topologies of Common Passive Filters

In this part, there is Design and calculation of parameters in Cubic Single Harmonized Filter.As illustrated in Fig. 3, a single harmonized filter is structured in the form of connection of the filter C, L and R. Fundamental capacitance value X_{C1}, rated voltage U_{CN} and the installed capacity Q_{CN} of single harmonized filter at the resonance frequency ω_h. They satisfied the following relationship:

$$X_{C1} = \frac{3U_{CN}^2}{Q_{CN}} \quad (1)$$

The system only had the fundamental voltage on the bus U_{C1}. As the system and the filter branch were connected in parallel, each filter branch had the appropriate number of harmonic currents I_h to flow through, plus the part that should be the current generated from the fundamental voltage $I_{1(h)}$. The size of the fundamental current that flowed through the filtration wave branch can be determined as follows:

$$I_{1(h)} = \frac{U_{C1}}{\frac{1}{\omega_1 C} - \omega_1 L} = \omega_1 C \frac{h^2}{h^2 - 1} U_{C1} \quad (2)$$

By introducing the over-voltage calibration formula, the capacitance of the capacitor is calculated as:

$$U_{C1} + \sum U_{Ch} \le 1.1U_{CN} \quad (3)$$

$$U_{C1} = \frac{X_{C1}}{X_{C1} - X_{L1}} U_M \quad (4)$$

Here U_M is the voltage limit actually running on the bus. At the filter resonance, there is:

$$X_{L1} = \frac{X_{C1}}{h^2} \quad (5)$$

Take (5) into (4). There is:

$$U_{C1} = \frac{h^2}{h^2 - 1} U_M \quad (6)$$

In an ideal situation, all the harmonic currents are shunt by the filter branch without being enlarged, when the filter is in the ideal resonance state, that is $Z_h = R_h$, the capacitor has only h harmonic current I_h and part of the fundamental current $I_{1(h)}$ flowing through it. At this point, there is:

$$HRU_h = \frac{U_h}{U_1} = \frac{I_h R_h}{U_1} \quad (7)$$

HRU_h is the content of h th harmonic voltage, because:

$$R_h = \frac{X_{C1}}{hQ} \quad (8)$$

Here Q is the quality factor, the size of its value in relation to the filtering effect. Generally, the value is between 30 and 60, here $Q = 30$.

So there is:

$$HRU_h = \frac{I_h}{U_1} \bullet \frac{X_{C1}}{hQ} = \frac{U_h}{U_1 Q} \quad (9)$$

In the above formula U_h, harmonic voltage magnitude requires $U_h = HRU_h U_1 Q$, there are:

$$U_{CN} = \frac{1}{1.1}\left(\frac{h^2}{h^2 - 1} U_M + HRU_h U_1 Q \right) \quad (10)$$

$$Q_{CN}=\frac{3U_{CN}^2}{X_{C1}}=\frac{3U_{CN}^2 I_h}{HRU_h QhU_1} \quad (11)$$

The installed capacity was determined in accordance with the check formula for a balanced capacity, then there is $Q_{CN}=Q_{C1}+\sum Q_h$. Likely, the only consideration goes to part of I_h and $I_{1(h)}$ coming through the filter , then:

$$Q_{CN}=3U_{CN}^2\omega_1 C\text{ ; }Q_{C1}=3U_{C1}^2\omega_1 C\text{ ;}$$

$$Q_h=3U_h^2 h\omega_1 C=\frac{3I_h^2}{h\omega_1 C}$$

$$Q_{CN}=\frac{3I_h U_{CN}^2}{\sqrt{h}\sqrt{U_{CN}^2-\left(\frac{h^2}{h^2-1}U_M\right)^2}} \quad (12)$$

Apart from the formula (2) and (12), the choice of capacitance is required to satisfy overcurrent conditions. Its check formula is:

$$\sqrt{I_{C1}^2+\sum I_h^2}\le 1.3I_{CN} \quad (13)$$

$$I_{C1}=U_{C1}\omega_1 C\text{ ; }I_h=U_h h\omega_1 C\text{ ;}$$

$$I_{C1}^2+\sum I_h^2=\left(1.3I_{CN}\right)^2$$

Therefore, there is:

$$\frac{U_{C1}^2}{X_{C1}^2}+I_h^2=1.69\frac{U_{CN}^2}{X_{C1}^2}\text{ ; }X_{C1}=\frac{3U_{CN}^2}{Q_{CN}}\text{ ; }U_{C1}=\frac{h^2}{h^2-1}U_M$$

$$\left(\frac{h^2}{h^2-1}U_M\right)^2\times\left(\frac{Q_{CN}^2}{3U_{CN}^2}\right)^2+I_h^2=1.69U_{CN}^2\left(\frac{Q_{CN}^2}{3U_{CN}^2}\right)^2 \quad (14)$$

Therefore, there is:

$$Q_{CN}=\frac{3U_{CN}^2 I_h}{\sqrt{1.69U_{CN}^2-\left(\frac{h^2}{h^2-1}U_M\right)^2}} \quad (15)$$

Of all the installed capacity values calculated by the above three checksum ways, the maximum value was selected as the installed capacity of the filter capacitor, and finally, to calculate the value of the capacitor:

$$C=\frac{Q_{CN}}{3\omega_1 U_{CN}^2} \quad (16)$$

According to the method of formula calculation, take the third filter design, for example, by measuring that $U_M=6050\text{V}$, in the 3-time filter branch, the formula (10) was used to calculate the capacitor's rated voltage:

$$U_{CN}=\frac{1}{1.1}\left(\frac{h^2}{h^2-1}U_M+U_3 Q\right)=\frac{1}{1.1}\left(\frac{3^2}{3^2-1}\times 6050+180.86\times 30\right)=11120\text{V}$$

Using the formula (13), (14) and (16), the capacitor rated voltage were used to calculate the capacitance that meet over-voltage, overcurrent and the capacity balancing conditions, of which the largest value was selected as the installed capacity of the capacitor.

$$Q_{CN}=\frac{3U_{CN}^2}{X_{C1}}=\frac{3U_{CN}^2 I_h}{HRU_h QhU_1}=\frac{3\times 11120^2\times 56.06}{180.86\times 30\times 3}=1277.6\text{kVar}$$

$$Q_{CN}=\frac{3I_h U_{CN}^2}{\sqrt{h}\sqrt{U_{CN}^2-\left(\frac{h^2}{h^2-1}U_M\right)^2}}=\frac{3\times 56.06\times 11120^2}{\sqrt{3}\sqrt{11120^2-\left(\frac{3^2}{3^2-1}\times 6050\right)^2}}=1365.4\text{kVar}$$

$$Q_{CN}=\frac{3U_{CN}^2 I_h}{\sqrt{1.69U_{CN}^2-\left(\frac{h^2}{h^2-1}U_M\right)^2}}=\frac{3\times 11120^2\times 56.06}{\sqrt{1.69\times 11120^2-\left(\frac{3^2}{3^2-1}\times 6050\right)^2}}=1630.6\text{kVar}$$

According to the value of the third filter Q_{CN}, and then calculate the C size of in the filter branch:

$$C=\frac{Q_{CN}}{3\omega_1 U_{CN}^2}=\frac{1630.6\times 10^3}{3\times 314\times 11120^2}=13.99\times 10^{-6}\text{F}$$

With these capacitance parameters, inductance value can be determined according to the relationship between inductance and capacitance in the single harmonized filter $h\omega_1 L=1/h\omega_1 C$, namely:

$$L=\frac{1}{h^2\omega_1^2 C}=\frac{1}{3^2\times 314^2\times 13.99\times 10^{-6}}=8.055\times 10^{-2}\text{H}$$

The above calculations of C and L are then followed by determining the resistance R size of the filter branch, by way of:

$$R=\frac{X_0}{Q}=\frac{h\omega_1 L}{Q}=\frac{3\times 314\times 8.055\times 10^{-2}}{30}=2.53\Omega$$

In the above formula, Q is the same quality factor. From the formula (8), the greater the value of the quality factor Q, the smaller the value of resistance R in the filter branch, and also the higher the sensitivity of the filter. Nonetheless, it's not always a better filtering effect comes from a better value Q. Too large a quality factor may encounter the deviation that occurs in the design process of the filter capacitor and reactor parameters, leading to a detuning result that cannot achieve the desired filtering effect. If Q is too small, then the loss of the fundamental incurred by filters could be increased, so the size of Q is generally controlled within the range of 30 to 60. Here, 30 is taken for calculation.

Analysis given on the waveform of the third filter branch indicated that the current flowing into the third filter branch was not the ideal sinusoidal waveform, where the amplitude maximum was app. 65A. This is because the harmonic filtration, due to the role of fundamental voltage applied to the filter branch, came along with the presence of some of the fundamental current shunt in the filter branch in parallel. Alternatively, in addition to the 3rd harmonic filtered, part of the fundamental wave also flowed through the filter branch. For a single harmonized filter, each branch would be more or less given a share of the harmonics. Here Formula (2) is used to calculate the fundamental current flowing through the third filter:

$$I_{1(h)} = \frac{U_{C1}}{\frac{1}{\omega_1 C} - \omega_1 L} = \omega_1 C \frac{h^2}{h^2 - 1} U_{C1} = 314 \times 1.399 \times 10^{-5} \times \frac{3^2}{3^2 - 1} \times 6 \times 10^3 = 29.65\text{A}$$

Based on the theoretical formula (2), there was 29.65A fundamental current flowing into the third filter branch. By performing components analysis using simulation models, it could be found that the measured fundamental current was 30.04A, being quite close to the value calculated by theoretical formulas. From the diagram, the analog filter was built in line with the theory basis. Similar design and calculation of parameters were completed on other single harmonized filters. Depending on the size of harmonics in their respective frequencies, the value of each parameter in each filter branch was determined. As for filter design, there was a need to check the over-voltage, over-current and capacity balance. Nevertheless, prior to the design, the larger capacity selected by checking was taken as the installed capacity, with its value being able to certainly meet the checking requirements, hence no need for a separate check.

III HARMONIC CONTROL OF BAR PLANT:

SIMULATION AND DESIGN

A. Analysis And Simulation Beforehand

By combining the power supply system with an equivalent electrical schematic with the filter system, the single harmonized filter branch and the high-pass filter branch were connected in parallel to the systems. The target bar plant used a 6/0.4kV transformer to supply power to each production unit. According to the load characteristics of the plant, it was decided that the filtering means was provided on the 6kV bus.

By use of the system model, the harmonic current was injected into the systems based on the given value. Before the filter was put in use, current waveform could be displayed on the oscilloscope system, as shown in Fig. 4. Since the harmonic current in the system exceeded the predetermined standard value, the resulting waveform distortion caused it no longer to be a inusoidal waveform in standard case.

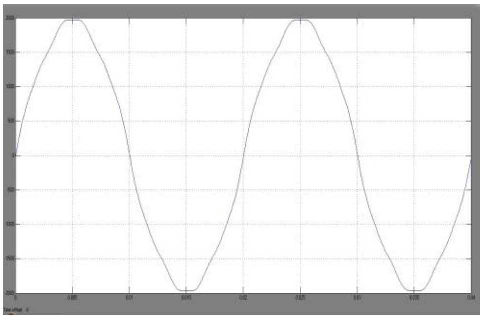
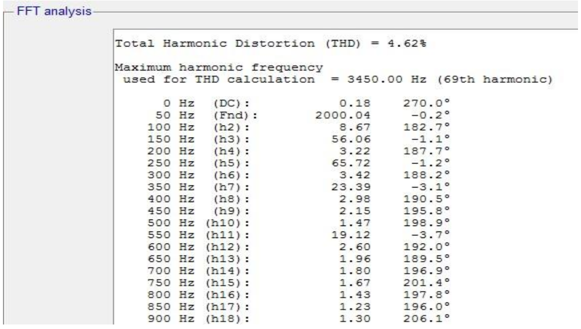


Figure 4 Current Waveform Before Filtering

The specific FFT analysis on the current in the analog system was performed with the help of the Powergui module. The values of harmonic currents and the current spectrum analysis are shown in Fig. 5 and Fig. 6, respectively. Obviously, before filtering process began, harmonic currents flowing into the system were quite large, and accompanied by different degrees of deformation. These deformations, if not filtered out, could pose a great impact on the operation of the system.



FFT analysis

Total Harmonic Distortion (THD) = 4.62%

Maximum harmonic frequency
used for THD calculation = 3450.00 Hz (69th harmonic)

0 Hz	(DC):	0.18	270.0°
50 Hz	(Fnd):	2000.04	-0.2°
100 Hz	(h2):	8.67	182.7°
150 Hz	(h3):	56.06	-1.1°
200 Hz	(h4):	3.22	187.7°
250 Hz	(h5):	65.72	-1.2°
300 Hz	(h6):	3.42	188.2°
350 Hz	(h7):	23.39	-3.1°
400 Hz	(h8):	2.98	190.5°
450 Hz	(h9):	2.15	195.8°
500 Hz	(h10):	1.47	198.9°
550 Hz	(h11):	19.12	-3.7°
600 Hz	(h12):	2.60	192.0°
650 Hz	(h13):	1.96	189.5°
700 Hz	(h14):	1.80	196.9°
750 Hz	(h15):	1.67	201.4°
800 Hz	(h16):	1.43	197.8°
850 Hz	(h17):	1.23	196.0°
900 Hz	(h18):	1.30	206.1°

Figure 5 Harmonic Currents Before Filtering

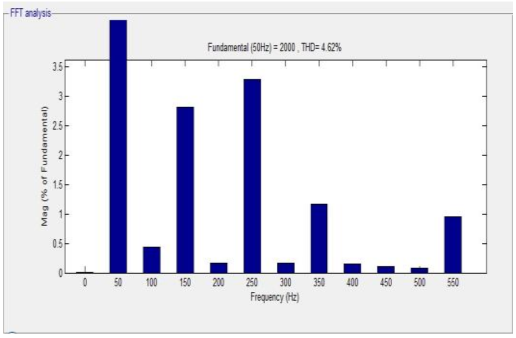
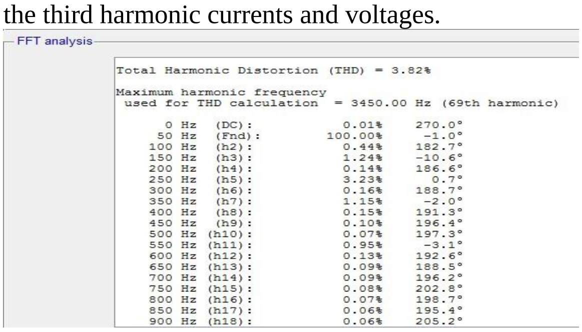


Figure 6 Current Spectrum Analysis Before Filtering

The third filter parameters was set up and used as illustrated in the filtering schematic. According to the theory, the access to the third filter allows most of the third harmonic to flow into the filter branch. In the system, the third harmonic currents will decrease in larger amplitude, and the current will have a total harmonic distortion that is to be reduced accordingly. After the model of the third filter came in running, the FFT analysis was performed for measurement on the system current, and the results are shown in Fig. 7 to 8. The data in the figures indicated that the system had its 3rd harmonic currents reduced from 56.06A down to 24.73A, comprising rate from 2.80% down to 1.24%. It is plain to see that the placement of the single harmonized third filter was capable of largely filtering the third harmonic currents and voltages.



FFT analysis

Total Harmonic Distortion (THD) = 3.82%

Maximum harmonic frequency
used for THD calculation = 3450.00 Hz (69th harmonic)

0 Hz	(DC):	0.01%	270.0°
50 Hz	(Fnd):	100.00%	-1.0°
100 Hz	(h2):	0.44%	182.7°
150 Hz	(h3):	1.24%	-10.6°
200 Hz	(h4):	0.14%	186.6°
250 Hz	(h5):	3.23%	0.7°
300 Hz	(h6):	0.16%	188.7°
350 Hz	(h7):	1.15%	-2.0°
400 Hz	(h8):	0.15%	191.3°
450 Hz	(h9):	0.10%	196.4°
500 Hz	(h10):	0.07%	197.3°
550 Hz	(h11):	0.95%	-3.1°
600 Hz	(h12):	0.13%	192.6°
650 Hz	(h13):	0.09%	188.5°
700 Hz	(h14):	0.09%	196.2°
750 Hz	(h15):	0.08%	202.8°
800 Hz	(h16):	0.07%	198.7°
850 Hz	(h17):	0.06%	195.4°
900 Hz	(h18):	0.06%	205.2°

Figure 7 Harmonic Current Content after the Placement of the Third Filter

```
FFT analysis
Total Harmonic Distortion (THD) = 3.82%
Maximum harmonic frequency
 used for THD calculation  = 3450.00 Hz (69th harmonic)
    0 Hz   (DC):          0.23     270.0°
   50 Hz  (Fnd):       2001.95      -1.0°
  100 Hz  (h2):           8.89     182.7°
  150 Hz  (h3):          24.73     -10.6°
  200 Hz  (h4):           2.90     186.6°
  250 Hz  (h5):          64.76       0.7°
  300 Hz  (h6):           3.20     188.7°
  350 Hz  (h7):          23.09      -2.0°
  400 Hz  (h8):           2.92     191.3°
  450 Hz  (h9):           2.01     196.4°
  500 Hz (h10):           1.37     197.3°
  550 Hz (h11):          18.96      -3.1°
  600 Hz (h12):           2.54     192.6°
  650 Hz (h13):           1.89     188.5°
  700 Hz (h14):           1.80     196.2°
  750 Hz (h15):           1.61     202.8°
  800 Hz (h16):           1.38     198.7°
  850 Hz (h17):           1.22     195.4°
  900 Hz (h18):           1.30     205.2°
```

Figure 8 Harmonic Current Value after the Placement of the Third Filter

B. Harmonic Spectrum Analysis After The Placement of All Filters

In accordance with the methods for the design and calculation of the third filter, the other single harmonized filter and high-pass filter parameters were calculated and brought into the established simulating system. The current waveforms filtered are referred in Fig. 9, respectively, from which it can be found they are close to sinusoidal waveform, preliminarily indicating a good filtering effect produced by the filter. FFT analysis was then given to the current filtered, with the resulting data as shown in Fig. 10-12.

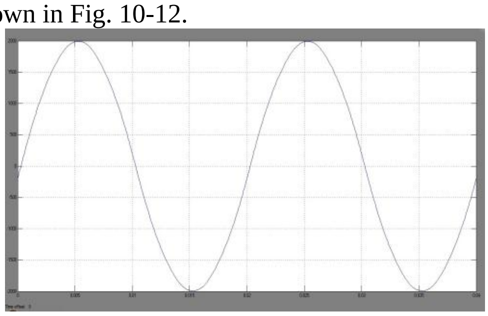


Figure 9 Current Waveform Filtered

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FFT analysis
Total Harmonic Distortion (THD) = 1.70%
Maximum harmonic frequency
 used for THD calculation  = 5500.00 Hz (110th harmonic)
    0 Hz   (DC):         0.00%      90.0°
   50 Hz  (Fnd):       100.00%      -5.1°
  100 Hz  (h2):          0.00%     -76.6°
  150 Hz  (h3):          1.48%     -16.8°
  200 Hz  (h4):          0.00%     -35.7°
  250 Hz  (h5):          0.80%     -26.2°
  300 Hz  (h6):          0.00%     222.6°
  350 Hz  (h7):          0.25%     -32.3°
  400 Hz  (h8):          0.00%     212.4°
  450 Hz  (h9):          0.00%      13.0°
  500 Hz (h10):          0.00%     -15.7°
  550 Hz (h11):          0.09%     -47.1°
  600 Hz (h12):          0.00%     167.6°
  650 Hz (h13):          0.00%     210.7°
  700 Hz (h14):          0.00%     243.3°
  750 Hz (h15):          0.00%     126.4°
  800 Hz (h16):          0.00%      69.9°
  850 Hz (h17):          0.00%     117.0°
  900 Hz (h18):          0.00%      38.7°
```

Figure 10 Current Content Filtered

```
FFT analysis
Total Harmonic Distortion (THD) = 1.70%
Maximum harmonic frequency
 used for THD calculation  = 5500.00 Hz (110th harmonic)
    0 Hz   (DC):          0.01      90.0°
   50 Hz  (Fnd):       2012.13      -5.1°
  100 Hz  (h2):           0.01     -76.6°
  150 Hz  (h3):          29.73     -16.8°
  200 Hz  (h4):           0.00     -35.7°
  250 Hz  (h5):          16.10     -26.2°
  300 Hz  (h6):           0.01     222.6°
  350 Hz  (h7):           4.99     -32.3°
  400 Hz  (h8):           0.01     212.4°
  450 Hz  (h9):           0.01      13.0°
  500 Hz (h10):           0.01     -15.7°
  550 Hz (h11):           1.84     -47.1°
  600 Hz (h12):           0.00     167.6°
  650 Hz (h13):           0.01     210.7°
  700 Hz (h14):           0.01     243.3°
  750 Hz (h15):           0.00     126.4°
  800 Hz (h16):           0.00      69.9°
  850 Hz (h17):           0.02     117.0°
  900 Hz (h18):           0.02      38.7°
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Figure 11 Current Value Filtered

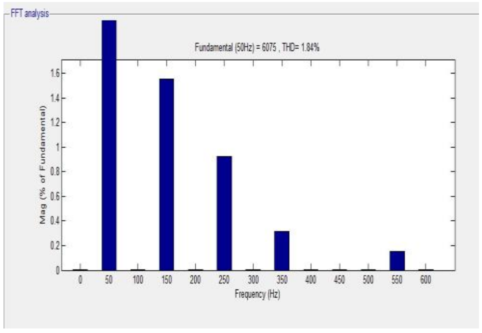

Figure 12 Spectrum Analysis after Filtering Current

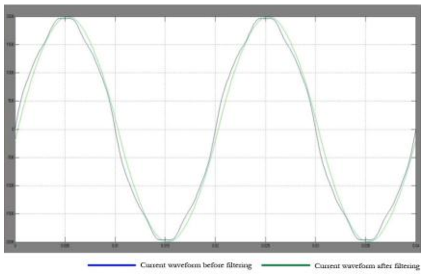

Figure13 Comparison Chart of Current Waveforms before Filtering

FFT analysis was then made on the spectrum of the harmonic current, after the placement of all filters, followed by comparison of the data in Table 2. Clearly, the contents of harmonic currents were all significantly reduced after filtering. Current waveforms before and after filtering are shown in Fig. 13. After all of the filters were placed, waveform was greatly improved to get close to a sine wave, where the desired filtering effect is further illustrated.

When all the single harmonized filters and high pass filters have been placed into the system, the measured harmonic current content as well as the total harmonic

TABLE II
Harmonic Current Content before and after Filtering

Harmonic times (Frequency)	Harmonic Current Size (A)		Harmonic current content (%)		Allowed values (A)	Excessive or not?	
	Before filtering	After filtering	Before filtering	After filtering		Before filtering	After filtering
3 times	56. 06	29. 73	2. 80	1. 84	34	Excessive	Qualified
5 times	65. 72	16. 10	3. 29	0. 8	34	Excessive	Qualified
7 times	23. 39	4. 99	1. 17	0. 25	14	Excessive	Qualified
11 times	19. 12	1. 84	0. 96	0. 09	16	Excessive	Qualified

distortion rate in the system after filtering were compared with the previous data. It can be found that after the filtering process, the third harmonic current was reduced from the previous 56. 06A to 29.73A; the fifth harmonic current was reduced from 65. 72A before filtering down to 16.10A; the 7th and 11th, respectively, reduced to 4.99A and 1.84A; all values had fallen within the range prescribed by the State, THD_U and more impressively, 5.44% that was never in line with the standard was significantly reduced to 1.84%, with the filtered waveform in line with national standards.

Through the comparison of the currents before and after filtering, we can see that the filtered harmonic current was able to meet the requirements; i. e. the designed filter can be used to effectively suppress and eliminate the harmonic current in the system.

IV Conclusions

This paper is mainly focused on how to test the harmonic current with rectifying devices available in a bar rolling mill and the corresponding measures for achieving harmonic control. Specifically, harmonic control works with a low-cost passive filter to design a proper content of the harmonic current for filtering purpose, which is safe and reliable, and proven to be a filtering system being more economical and desirable.

This designed filter also performed the FFT analysis on harmonic current in measurement system. The result revealed that most of the harmonic current after filtering flowed into the corresponding harmonic branches. The harmonic current injected into the system came down to a great extent, reaching the allowable value as specified. The filtering process in this design ended with satisfied results, and thus has been widely adopted due to the low cost and stable operation of passive filters included. This work was concluded by conducting simulation to verify the validity of the designed program.

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