Investigation of Harmonic Reduction Using Passive Filters in a Distribution Network in Basra City

Salam B Abood\(^1\) and Thamir M Abdul-Wahhab\(^2\)

\(^1\)Ministry of Electricity, Iraq
\(^2\)Department of Electrical Engineering, University of Technology, Iraq

Abstract. Harmonics in current and voltage waveforms produced by nonlinear loads in a distribution system can be minimised using passive filters; however, implementing these filters requires the calculation of several suitable parameters for filter components. This work aimed to simulate and analyse the harmonics in the Al-Itihad 11 kV distribution system that branches off from Zubayr substation (33/11 kV) in Basra in Iraq using MATLAB/SIMULINK. Five nonlinear loads were simulated to generate harmonics in the simulated Al-Itihad distribution system, and for each non-linear load three types of filters were tested: a single tuned filter (STF), double tuned filter (DTF), and C-type filter. The objectives of these filters to minimise the total harmonic distortion (THD) in the voltage and current waveforms, to minimise the total current, and to improve the power factor of the distribution system. The simulation results showed a reduction in total harmonic distortion, a reduction in the current at the main distribution feeder, and an improvement in the power factor of the feeder.

1. Introduction

Nonlinear loads in power system such as powerful electronic devices increase the distortion of the voltage and current waveforms, which leads to harmonics in these waveforms. Such harmonics have a negative effect on the electric power system, potentially increasing electrical losses, reducing the power factor, and encouraging over loading which may lead to equipment failure [1, 2].

Many techniques have been used to minimise these harmonics, particularly filters on the electric power system, including active filters (AF) and passive filters (PF) [3, 4]. Active filters generally offer good performance, though this comes with several disadvantages such as complexity of design and high cost [3]. Passive filters have other advantages, such as simplicity of design and structure, low cost, and raid responses, as they consist of resistors, inductors, and capacitors and do not require external power sources. However, precise calculation of suitable parameters for these filter components in electric power systems is required to minimise the harmonics and prevent distortion of the voltage and current waveforms [5, 6].

2. Distribution System Simulation

The feeder distribution system branching off from Zubayr substation (33/11 kV) in Basra city, the Al-Itihad 11 kV system, was selected to implement this work. This system consists of 15 buses and 12 loads (11/0.4 kV transformers), as shown in figures 1.a and 1.b.
Figure 1. Al-Itihad 11 kV distribution system, (a) photograph, (b) Single-line diagram.

2.1 Simulation of Distribution Lines
A distribution line can be represented by its resistance and inductance (self and mutual reactance) connected in series. The resistance and inductance of a distribution line can then be calculated using the following equations [7]:

\[ \text{Resistance} = \frac{\text{Voltage Difference}}{\text{Current}} \]

\[ \text{Inductance} = \frac{\text{Voltage Difference}}{\text{Current}} \times j \omega \]

where \( j \) is the imaginary unit, and \( \omega \) is the angular frequency.
\[ R = R_{20}[1 + \alpha_{20}(t - 20)] \]  

(2.1)

where, \( R(\Omega) \) is the resistance of the conductor, and \( t \) is the ambient temperature at which the wire resistance \( R \) is to be calculated. According to the specifications of the Ministry of Electricity (MOE), \( R = 0.2375 \Omega/\text{km} \) at 20°C, and \( \alpha_{20} = 0.00404 \) for aluminium conductor. Conductor resistance at 50°C is therefore

\[ R = 0.2375[1 + 0.00404(50 - 20)] = 0.2662 \Omega/\text{km} \]

The arrangement of the three phase conductors is shown in Figure 2.

![Figure 2. Three-phase arrangement.](image)

Thus, the inductance can be calculated using the following equation:

\[ L = 2 \times 10^{-7} \ln \left( \frac{D_{eq}}{\bar{r}} \right) \times l \]  

(2.2)

where \( L \) is the line inductance, \( D_{eq} = \sqrt{D_{ab}D_{bc}D_{ca}} \), \( D \) is the distance between two conductor, and \( \bar{r} = 0.812r \), where \( r \) is the radius of the conductor and \( l \) is the line length (m). For ACSR 120/20 mm², \( r = 15.5/2 = 7.75 \) mm. According to the Ministry of Electricity, Iraq (DIN 28204), \( L = 1.042 \) mH/km.

The resistances and inductances for Al-Itihad distribution lines were thus calculated based on actual line lengths using equations (2.1) and (2.2); these figures are given in Table 1.

| L (mH) | R (Ω) | Length (m) | Lines |
|-------|-------|------------|-------|
|       |       |            | To    | From |
| 0.527 | 0.135 | 505        | 1     | 0    |
| 0.100 | 0.025 | 96         | 2     | 1    |
| 0.117 | 0.030 | 113        | 3     | 2    |
| 0.182 | 0.046 | 175        | 4     | 3    |
| 0.038 | 0.008 | 37         | 5     | 4    |
| 0.010 | 0.0026| 10         | m     | 5    |
| 0.091 | 0.023 | 88         | 6     | m    |
| 0.068 | 0.017 | 66         | 7     | m    |
| 0.060 | 0.015 | 58         | n     | 7    |
| 0.129 | 0.033 | 124        | 8     | n    |
| 0.070 | 0.018 | 68         | 9     | n    |
| 0.039 | 0.010 | 38         | 12    | n    |
| 0.044 | 0.011 | 43         | h     | 9    |
| 0.059 | 0.015 | 57         | 10    | h    |
The Al-Itihad distribution system was simulated using MATLAB/SIMULINK, as shown in Figure 3.

| 0.052 | 0.013 | 50   | 11  | h  |
|-------|-------|------|-----|----|
| 0.070 | 0.018 | 68   | 13  | 12 |
| 0.033 | 0.008 | 32   | 14  | 12 |
| 0.122 | 0.031 | 118  | 15  | 14 |

2.2 Simulink Model of Al-Itihad Distribution System
2.3 Simulation of non-linear loads

The non-linear loads in the distribution system were simulated using a three-phase rectifier with resistance and capacitor loads, such as converters from AC to DC. Figure 4 shows the simulation model for one such non-linear load.
Non-linear loads were added to buses 15, 16, 17, 18, and 19 in the simulated Al-Itihad distribution system to act as harmonic generators in the distribution system. Figure 5 shows the Al-Itihad distribution system with the five added non-linear loads.

3. Harmonic Filters
In this work, only passive filters were used. The most common types of passive filters are

3.1 Single Tuned Filter [8, 9, 10]
The single tuned filter (STF) selected was a low pass filter, as shown in Figure 6 [8]. The capacitor reactance value $X_c$ was given by [10]

$$X_c = \frac{V^2}{Q} \quad (3.1)$$

where $V$ is the line to line rated voltage of the capacitor and $Q$ is the reactive power of the capacitor. The filter’s capacitance was then calculated using

$$C = \frac{1}{2\pi f X_c} \quad (3.2)$$

where $f$ is the fundamental frequency. The reactor value of the filter was then obtained using

$$L = \frac{1}{(2\pi fn)^2 C} \quad (3.3)$$

where $n$ is the harmonic order to which the filter is tuned. The value of the resistance, $R$, determines the quality factor ($q$) of the filter. This is equal to the ratio of the inductive or capacitive reactance at resonance to the resistance. Typical values of $q$ range from 15 to 100 for the filters commonly used in industrial and commercial applications [10]. The resistance was calculated by using:[8]

$$R = \frac{X_n}{q} \quad (3.4)$$

where $X_n$ is the characteristic reactance such that

$$X_n = \sqrt{X_L X_c} \quad (3.5)$$

### 3.2 Double Tuned Filter [11]

The Double Tuned Filter (DTF) operates to minimise two levels of harmonics simultaneously, as shown in Figure 7. Series resonance circuit ( $L_1$, $C_1$) and parallel resonance circuit ( $L_2$, $C_2$) respectively have resonance frequency $\omega_s$ and $\omega_p$. They can be expressed as

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}} \quad (3.6)$$

$$\omega_p = \frac{1}{\sqrt{L_2 C_2}} \quad (3.7)$$

Two parallel single tuned filters are shown in Figure 8. Their resonance frequencies can be expressed as

$$\omega_a = \frac{1}{\sqrt{L_a C_a}} \quad (3.8)$$

and
\[ \omega_b = \frac{1}{\sqrt{L_b C_b}} \quad (3.9) \]

respectively.

Two parallel single tuned filters and a double-tuned filter are equivalent; thus

\[ \omega_a \omega_b = \omega_s \omega_p \quad (3.10) \]

\( C_1 \) is calculated based on the two capacitors \( C_a \) and \( C_b \) having two order harmonics:

\[ C_1 = C_a + C_b \quad (3.11) \]

The parameter \( L_1 \) can then be calculated as

\[ L_1 = \frac{1}{\omega_a \omega_b^2 + \omega_b \omega_p^2} \quad (3.12) \]

Using \( L_1 \) and \( C_1 \), the series resonance frequency \( \omega_s \) and parallel resonance frequency \( \omega_p \), can be calculated:

\[ \omega_s = \frac{1}{\sqrt{L_1 C_1}} \quad (3.6) \]

\[ \omega_p = \frac{\omega_a \omega_b}{\omega_s} \quad (3.13) \]

and the parameters \( L_2 \) and \( C_2 \) can be calculated as

\[ L_2 = \frac{C_1 \omega_p^2}{\left(1 - \frac{\omega_s^2}{\omega_p^2}\right) \left(1 - \frac{\omega_s^2}{\omega_p^2}\right)} \quad (3.14) \]

\[ C_2 = \frac{1}{L_2 \omega_p^2} \quad (3.15) \]

### 3.3 C-Type Filter

C-type filters [12, 13] are second-order filters with the capacity to suppress harmonic currents with lower losses than a series filter or band-pass filter, as shown in Figure 9. C-type filters perform particularly well in terms of suppressing high frequency harmonics. The parameters of the C-type filter are calculated by using the following equations [12]:

\[ C_1 = \frac{Q}{\omega_1 V^2} \quad (3.16) \]

\[ C_2 = C_1 (n^2 - 1) \quad (3.17) \]

\[ L = \frac{1}{\omega_1 C_2} \quad (3.18) \]

\[ R = \frac{V^2}{\omega_1 L_s k n^2 Q^2 \sqrt{V^4 - \omega_1^2 L_s^2 k^2 n^4 Q^2}} \quad (3.19) \]

where

- \( \omega_1 \) – the fundamental angular frequency,
- \( V \) – the line to line rated voltage of the filter,
- \( n \) – harmonic order of filter tuning
- \( k \) – the assumed harmonic flow ratio,
$Q$ – the C-type filter reactive power,
$L_s$ – the equivalent inductance of the power grid.

4. Harmonic Indices
The two indices most commonly used to measure the harmonic content of a waveform are the Total Harmonic Distortion for current ($THDi$) and Total Harmonic Distortion for voltage ($THDv$) [10]. The $THDi$ and $THDv$ can be calculated using the following equations [4, 14]:

$$THDi = \frac{1}{I_1} \sqrt{\sum_{n=2}^{\infty} (I_n)^2}$$  \hspace{1cm} (4.1)

$$THDv = \frac{1}{V_1} \sqrt{\sum_{n=2}^{\infty} (V_n)^2}$$  \hspace{1cm} (4.2)

where $n$ is the order of harmonics, $I_n$ and $I_1$ are the harmonic and fundamental currents, and $V_n$ and $V_1$ are the harmonic and fundamental voltages.
According to the IEEE 519 standard, the THD of voltage ($THDv$) must be less than 5%, while the THD of current ($THDi$) can vary from a few percent to more than 100% [15].

5. Distribution System Model with Non-Linear Loads and Filters
To address the five non-linear loads added to buses 15, 16, 17, 18, and 19 in the Al-Itihad distribution system, five filters were added to minimise the harmonics, as shown in Figure 10.
Figure 10. Simulation model of the Al-Itihad distribution system with five non-linear loads and filters.

6. Harmonic Analysis of the Al-Itihad Distribution System
The non-linear loads in Al-Itihad distribution system injected harmonics that disturbed the current waveform. The current waveforms for non-linear loads in buses 16 and 19 are shown in figures 11 and
12 as an example. The harmonic spectrum for all loads indicates high harmonics of the fifth and seventh order.

![Image of harmonic spectrum for bus 16 with non-linear load](image1.png)

**Figure 11.** Current waveform and harmonic spectrum for bus 16 with non-linear load.

![Image of harmonic spectrum for bus 19 with non-linear load](image2.png)

**Figure 12.** Current waveform and harmonic spectrum for bus 19 with non-linear load

The current, voltage, power factor, and THD in the main feeder bus 0 when the 5 non-linear loads are applied in the system were measured as given in Table 2. Figure 13 shows the overall current waveform and harmonic spectrum.
### Table 2. Main feeder bus 0: current, voltage, power factor, THDv, and THD, measured using MATLAB/SIMULINK for a system with non-linear loads

| $i_{\text{total}}$ (A) | Voltage (V) | Power factor | THDv (%) | THD, (%) |
|------------------------|-------------|--------------|----------|----------|
| 312.4                  | 11000       | 0.7196       | 8.702    | 12.14    |

### Figure 13. Current waveform and harmonic spectrum for main feeder bus 0 with non-linear loads

#### 7. Calculation of Power Filter Parameters

Three types of power filters, the single tuned filter (STF), the double tuned filter (DTF), and the C-type filter, were used to minimise the harmonics in Al-Ithad distribution system. These passive filters’ parameters were calculated using the appropriate filter equations given in section 3 for each type. The harmonics generated from the non-linear loads in this work were of the fifth and seventh order, with the filter parameters thus computed to remove these harmonics. Tables 3, 4, and 5 give the proposed STF, DTF, and C-type filter parameters, respectively.

### Table 3. Proposed STF parameters

| STF Parameters | Values       |
|----------------|--------------|
| R              | 0.00896 Ω    |
| L              | 0.06 mH      |
| C              | 7.45 mF      |

### Table 4. Proposed DTF parameters
### Table 5. Proposed C-type filter parameters

| C-type Parameters | Values      |
|-------------------|-------------|
| $C_1$             | 8 mF        |
| $L_1$             | 0.52 µH     |
| $C_2$             | 0.192 F     |
| $R$               | 30 Ω        |

8. Connecting Power Filters to the Al-Itihad Distribution System

Harmonics were calculated in the Al-Itihad distribution system after connecting each type of filter with regard to each non-linear load.

8.1 Results of Connecting STF to the Al-Itihad Distribution System

The results of connecting STF to each non-linear load are shown in Figure 14 by the current waveforms and harmonics spectrum of currents as measured using MATLAB/SIMULINK on main feeder bus 0. The harmonic of the fifth order in the current waveform was reduced in the distribution system from 7% to 5%, while the harmonic of seventh order in the current waveform was reduced in the distribution system from 3.75% to 3.25%. Other harmonics were also reduced by connecting the STF to the system. The THD in the currents on the main feeder was reduced from 12.10% to 9.781%, as shown in Figure 17, while the current was reduced from 312.4 to 308.8 A, and the power factor improved from 0.7196 to 0.9029. Table 6 shows the main feeder measurements with STF connected.
Figure 14. Current waveform and harmonic spectrum for main feeder bus 0 with STF connected to each non-linear load

Table 6. Main feeder measurements with STF connected

| $i_{\text{total}}$ (A) | Voltage (V) | Power factor | THDv (%) | THDi (%) |
|------------------------|-------------|--------------|----------|----------|
| 308.8                  | 11000       | 0.9029       | 5.231    | 9.781    |

8.2 Results of Connecting DTF to the Al-Itihad Distribution System

The results of connecting the DTF to each non-linear load are shown in Figure 15 by the current waveforms and harmonic spectrum of currents as measured using MATLAB/SIMULINK on main feeder bus 0. The harmonic of the fifth order in the current waveform was reduced in the distribution system from 7% to 2.75%, while the harmonic of seventh order in the current waveform in the distribution system dropped from 3.75% to 3.2%. Other harmonics were also reduced on connecting the DTF to the system, with the THD on the main feeder reduced from 12.10% to 9.213%, as shown in Figure 17, and the current falling from 312.4 to 305.8 A. Moreover, the power factor improved from 0.7196 to 0.8953. Table 7 shows the main feeder measurements with DTF connected.
Figure 15. Current waveform and harmonic spectrum for main feeder bus 0 with DTF connected to each non-linear load.

Table 7. Main feeder measurement with DTF connected

| $i_{total}$ (A) | Voltage (V) | Power factor | THDv (%) | THDi (%) |
|----------------|-------------|--------------|----------|----------|
| 305.8          | 11000       | 0.8953       | 4.935    | 9.213    |

8.3 Results of Connecting C-Type Filters to the Al-Ithad Distribution System

The results of connecting a C-Type filter to each non-linear load are shown in Figure 16 as the current waveforms and harmonic spectrum of currents as measured using MATLAB/SIMULINK on main feeder bus 0. The harmonics of the fifth order in the current waveform were reduced in the distribution system from 7% to 0.75%, while the harmonics of the seventh order in the current waveform were reduced from 3.75% to 3%. Other harmonics were also minimised by connecting the C-Type filter to the system, with the THD on the main feeder falling 12.10% to 8.748%, as shown in Figure 17. The current was reduced from 312.4 to 306.8 A, while the power factor improved from 0.7196 to 0.9083. Table 8 shows the main feeder measurements with C-type filters connected.
Figure 16. Current waveform and harmonic spectrum for main bus 0 feeder with a C-type filter connected to each non-linear load

Table 8. Main feeder measurements with C-Type filters connected

| $i_{tot}$ (A) | Voltage (V) | Power factor | THDv (%) | THDi (%) |
|---------------|-------------|--------------|----------|----------|
| 306.7         | 11000       | 0.9083       | 4.321    | 8.748    |

9. Improvement in THD

Figure 17 shows a comparison of THDi results for the Al-Ithad distribution system without and with the various passive filters connected. The results for THD in main feeder bus 0 of the Al-Ithad distribution system were 12.14% before filter connection, 9.781% after connecting STF filters, 9.213% after connecting DTF filters, and 8.748% after connecting C-type filters. Connecting the C-Type filter to the distribution system thus gives the best results in terms of obtaining the minimum values of THD, as shown in Figure 17.
10. Improvements in Power Factor, Current, and THDv in the Main Feeder

All passive filters improved the power factor. The power factor measurements in the main feeder were 0.9029 for STF, 0.8953 for DTF, and 0.9083 for C-type filters. The C-type filters gave the best improvement in power factor, as shown in Figure 18.

The results for total currents were 308.8 A for STF, 305.8 A for DTF, and 306.7 A for C-type filters. DTF thus gave the lowest drawn current in the main feeder, as shown in Figure 19.

The results for THDv were 5.231% for STF, 4.935% for DTF, and 4.321% for C-type filters. The C-type filters gave the lowest THDv in the main feeder, as shown in Figure 20.

The results overall suggest that the C-type filters offer the best harmonic distortion THDv reduction due to high harmonic mitigation, as the C-type filters are broadband filters, as well as the best improvement in power factor, reducing the reactive power in the power system. They also ensure reduction of active power losses, as the $L C_2$ branch (Fig. 9) is tuned to the fundamental harmonic frequency. The fundamental harmonic current also does not pass through the resistor $R$, avoiding any large power losses.

Figure 18. Power factor on main feeder bus 0 without and with connected passive filters.
11. Conclusions

This work developed a simulated model to minimise harmonics in Al-Itihad distribution system (11kV) using passive filters. Three passive filters were applied to improve the distribution system through minimising the Total Harmonic Distortion factors THD$_v$ and THD$_i$. The simulation results showed that the C-type filter offered better results than STF and DTF filters in terms of minimising the harmonics in the current and voltage waveforms in the main feeder of the Al-Itihad distribution system. All power filters reduced the harmonics to meet the specifications of the IEEE 519-1992 Standard for current waveforms, however. Moreover, all power filters improved the power factor in the Al-Itihad distribution system, though C-type filters achieved the best results, and reduced the total current in the main feeder; DTF achieved the lowest drawn current values.
References

[1] B. I. Chaughule, A. L. Nehete and R. Shinde, “Reduction In Harmonic Distortion Of The System Using Active Power Filter In Matlab/Simulink”, International Journal of Computational Engineering Research, (3) 2013, 59-64.

[2] M. Davudi, S. Torabzad, and B. Ojaghi, “Analysis of Harmonics and Harmonic Mitigation Methods in Distribution Systems”, Australian Journal of Basic and Applied Sciences, (5) 2011, 996-1005.

[3] N. C. Yang, and M. D. Le, “Loop Frame of Reference Based Harmonic Power Flow for Unbalanced Radial Distribution Systems”, Electrical Power and Energy Systems, 77 (2016) 128–135.

[4] Kalaira, N. Abasb, A.R. Kalairc, Z. Saleemd, and N. Khan, “Review of harmonic analysis, modeling and mitigation techniques”, Renewable and Sustainable Energy Reviews 78 (2017) 1152–1187.

[5] A Kaushik, and J. Varanasi, “Harmonic Analysis in Power Systems Due to Non Linear Loads”, Proceedings of SARC-IRF International Conference, (2014) 22-26.

[6] P. K. Ray, and B. Subudhi, “Neuro-Evolutionary Approaches to Power System Harmonics Estimation”, Electrical Power and Energy Systems, 64 (2015) 212-250.

[7] V. Mehta and R. Mehta “Principles Of Power System”, S Chand & Co Ltd; 3rd edition (2012).

[8] D. Soomro and M. Almelian “Optimal Design of A Single Tuned Passive Filter to Mitigate Harmonics in Power Frequency”, ARPN Journal of Engineering and Applied Sciences (2015).

[9] R. Shaikh, A. Lashari and I. Ansari “Harmonics Analysis and Mitigation Using Passive Filters”, Mehran University Of Engineering & Technology, Jamshoro (2015).

[10] C. Venkatesh, D. S. Kumar, and D. V. S. S. Sarma, and M. Sydulu, “Estimation and Mitigation of Voltage and Current Harmonics in Distribution Systems”, IEEE Region 10 Conference TENCON, (2009) 19-21.

[11] H. Yi-hong and S Heng “New Method of Designing Double-tuned Filter”, Proceedings of the 2nd International Conference on Computer Science and Electronics Engineering (2013).

[12] R. Klempka “Design of C-Type Passive Filter for arc Furnaces”, Metalurgija (2017).

[13] R. Klempka “A New Method for the C-Type Passive Filter Design”, Electrical Review (2012).

[14] Y. Zhang “The Origin, Effect, and Suppression of Harmonics in Industrial Electrical Networks”, (1997).

[15] Buso, S., Malesani, L., Mattavelli, P. and Veronese, R., "Design and Fully Digital Control of Parallel Active Power Filters for Thyristor Rectifiers to Comply with IEC-1000-3-2 Standards, IEEE Transactions on Industry Applications, vol. 34, 1998, pp. 508-517.
### Appendix A

Type of feeder and features used in this work:

Table A-1: Aluminium Conductors Steel Reinforced (ACSR) DIN 48204 standard IEC 61089 [MOE].

| Code Number | Calculated Area | Standing & wire Diameter | Linear Mass | Overall Diameter | DC resistance at 20°C |
|-------------|-----------------|--------------------------|-------------|------------------|-----------------------|
|             | Al/Steel | Total | Al | Steel | Alum | Steel | Total | Mm | Kg/km | Kg/km | Mm | Ω/km |
| 15/2.5      | 15 3 | 17.8 | 6/1.60 | 1/1.80 | 42 | 20 | 62 | 5.4 | 1.8790  |
| 25/4        | 23.8 | 27.8 | 6/2.25 | 1/2.25 | 85 | 32 | 97 | 6.8 | 1.2032  |
| 35/6        | 34.3 | 40.0 | 6/2.70 | 1/2.70 | 54 | 46 | 140 | 8.1 | 0.3352  |
| 44/32       | 44.0 | 75.7 | 14/2.30 | 7/2.40 | 122 | 250 | 372 | 11.2 | 0.6573  |
| 50/8        | 48.3 | 56.3 | 6/3.20 | 1/3.20 | 132 | 64 | 196 | 9.6 | 0.5940  |
| 50/30       | 51.2 | 81.0 | 12/3.33 | 7/3.33 | 141 | 237 | 378 | 11.7 | 0.5643  |
| 70/12       | 69.9 | 81.3 | 26/1.35 | 7/1.44 | 193 | 91 | 264 | 11.7 | 0.4130  |
| 95/15       | 94.4 | 109.7 | 26/2.15 | 7/1.67 | 260 | 123 | 383 | 13.6 | 0.3058  |
| 95/55       | 96.5 | 152.8 | 12/3.20 | 7/3.20 | 266 | 446 | 712 | 16.0 | 0.2992  |
| 105/75      | 105.7 | 181.5 | 14/3.10 | 9/2.25 | 292 | 599 | 891 | 17.5 | 0.2735  |
| 120/20      | 121.06 | 198.1 | 26/2.44 | 7/1.90 | 336 | 158 | 494 | 15.5 | 0.2374  |

Table A-2: ACSR 120/20 mm² conductor DIN 48204 standard IEC 61089 [MOE].

| Description | Unit | Type - Denomination |
|-------------|------|----------------------|
| Overall diameter | mm | ACSR 120/20 mm² |
| Nominal cross section | mm² | ACSR 120/20 mm² |
| Stranding | strand | ACSR 120/20 mm² |
| Weight | daN/km | ACSR 120/20 mm² |
| Ultimate Tensile Strength (UTS) | kN | ACSR 120/20 mm² |
| Modulus of elasticity (final) | N/mm² | ACSR 120/20 mm² |
| Coefficient of linear expansion | 1/°C | ACSR 120/20 mm² |
| Rated DC resistance at 20 °C | Ω/km | ACSR 120/20 mm² |
| Current carrying capacity 80 °C | A | ACSR 120/20 mm² |
| Typical length on reel | m | ACSR 120/20 mm² |

**Standard**

|            |            | **DIN 48204** | **IEC 61089** | **DIN 48204** | **IEC 61089** |
|-------------|-------------|---------------|---------------|---------------|---------------|
| Overall diameter | mm | 15.5 | 20.27 |
| Nominal cross section | mm² | 141 | 243 |
| Stranding | strand | 26/7 | 26/7 |
| Weight | daN/km | 494 | 851 |
| Ultimate Tensile Strength (UTS) | kN | 44.94 | 74.94 |
| Modulus of elasticity (final) | N/mm² | 75510 | 75510 |
| Coefficient of linear expansion | 1/°C | 18.9 x10-6 | 18.9 x10-6 |
| Rated DC resistance at 20 °C | Ω/km | 0.2374 | 0.1380 |
| Current carrying capacity 80 °C | A | 440 | 630 |
| Typical length on reel | m | 2000 | 2000 |