Power Quality Problem In Iraqi Network And Its Mitigation Techniques

Mohammed Saleh AL-MAHMOOD[1]
[1]Power Electronics and Clean Energy Systems, Okan University, Istanbul, Turkey
mhamadsaleh4991@gmail.com , ORCID: 0000-0002-0251-7615

Ramazan Nejat TUNCAY[2]
[2]Department of Energy, Okan University, Istanbul, Turkey
nejat.tuncay@okan.edu.tr , ORCID: 0000-0002-1963-480X

ABSTRACT

Globally, the reliability of electricity networks is becoming a significant concern. The electrical grid must provide sinusoidal voltages and currents that are unvarying in frequency and amplitude. However, connecting non-linear loads causes harmonics to be produced, which lowers the grid's quality. Harmonics in load currents can cause several detrimental effects, including distortion of the voltage waveform at the point of common coupling. Therefore, harmonics must be reduced in order to maintain good grid quality. In this study, a brief information about the Iraqi power system is presented, and the non-linear load is connected on to 132 kV Hamam Al-aleel substation. The harmonics and its major impact on power systems with reference to harmonic distortion brought on by non-linear loads are discussed. The study show that when passive filters are used in parallel with the non-linear load, the harmonics in current waveform can be reduced and substantially enhance the power quality of the system.

Keywords: Power Quality, Harmonics, Passive Filters, Iraqi Power System, Non-Linear Load.

1. Introductıon

Electrical power quality is defined as the degree of variation from the rated value of voltage magnitude, power supply discontinuity, and frequency. Power quality refers to the degree that the use and distribution of electric power impact the operation of electrical equipment (Ogheneovo Johnson 2016). Voltage quality issues were evident, particularly prior to 1980 (Balasubramaniam and Prabha 2015). Residents relied solely on electricity for lighting, which was delivered via long low-voltage lines, resulting in very low voltage at the consumer's end. Modern electronic appliances, on the other hand, require high-quality power. To improve electric power system quality, medium voltage power substations are expected to be erected closer to residences (Tarasiuk et al. 2021). When power electronics devices, arc furnaces, and the penetration of renewable energy resources are grown in the power system, the distortion of the current and voltage waveforms will be evident to the end consumers and new techniques are required to mitigate this impact. Because of its importance in daily life, electricity supply and management are critical (Azadi, Akbari, and Sepasian 2018). Over the previous few decades, the Iraqi electric sector has experienced multiple losses as a result of regional, national, and international wars. Warfare and an unstable socioeconomic climate hampered the growth of the Iraqi electric power system.

This research shed light on issues that affected the quality of the Iraqi power system for the Nineveh governorate (which is located in the north of Iraq) when the non-linear load is connected at Hamam al-aleel 132 kV substation and the methods for mitigating the impact of the non-linear load on the power quality. This work also concentrates on the best strategies that needed to be used to overcome this hurdle that the Iraqi power system is facing with. For this purpose the MATLAB/SIMULINK model is established and the simulation of the local power system has been achieved for the evaluating the total harmonic distortion (THD). One of the most pervasive problems with power system quality is harmonic distortion. Harmonic currents are produced into the power system by nonlinear loads like power electronics, electric arc furnaces, and saturating magnetic equipment (Ulinuha and Sari 2021). Harmonics may damage spinning machinery, system lines, capacitors, and transformers, or generate high losses in automation systems. In particular, harmonics may cause electrical motors to produce pulsing torques as well as stimulate series and parallel resonances. Harmonic mitigation has been accomplished using a variety of techniques, including as passive/active filters, high-pulse rectification, and specialized power equipment (Mittal 2012).

2. Iraqi Power System Background

The generating, transmission, and distribution sections make up the building of power systems. The voltages in the generating section of the Iraqi electricity system are less than 20 kV. In the transmission industry, step-up transformers are utilized to boost for voltage levels to 132 kV and 400 kV. Transformers link the 132kV high voltage transmission with the 400kV extra high voltage transmission. In the distribution industry, step down transformers are utilized to reduce voltage levels to 33kV and/or 11kV (Yasen 2016). The installed capacity and the available generation in MW are shown Figure (1)(Joining et al. 2013) .

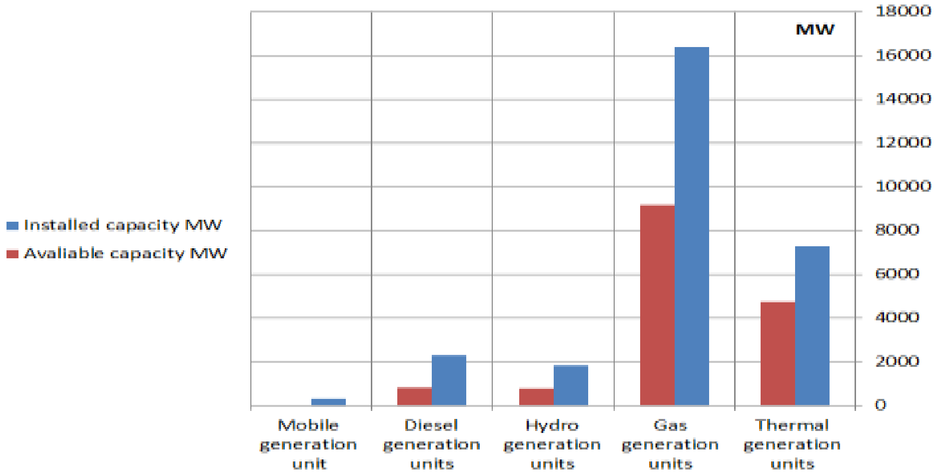


Figure 1. The Installed and available generation in Iraq (Joining et al. 2013)

Figure (2) shows the gap between the annual load demand with actual generation in MW for the period from 2011 to 2022, it can be clear to see there is a gap between the load demand and the generation and the load shedding strategy is applied in Iraqi power system to control the frequency. This gap it present from 1990 after the first gulf war, in future the Ministry of electricity have master plan to remove this gap at 2030 (Joining et al. 2013)(Reda et al. 2006).

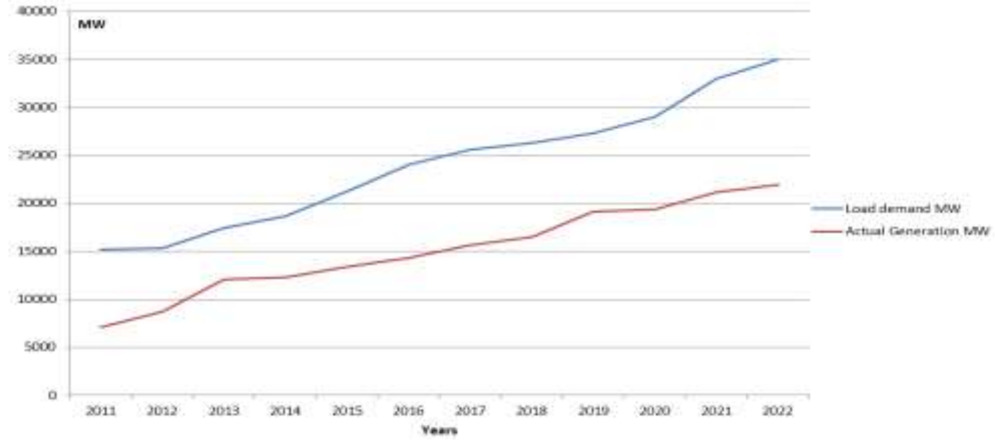


Figure 2. Load Demand and actual generation for the period 2011-2022 (Joining et al. 2013)

The rate of change of frequency in Iraqi power system is more fluctuated because of the high load demand as compared generated power, because of the high load demand; the voltage is also reduced according to the characteristics of the power voltage curve. The voltage profile can be improved by reconfigured and support the transmission lines as in the future M.o.E plan.

3. Power Quality Improving Techniques

Power quality issues are growing increasingly frequent as the number of power electronic devices increases, as does the prevalence of renewable energy in present power systems, requiring the new technical solutions. The two types of power quality improvement methodologies for power systems are voltage quality improvement (VQI) and current quality improvement (CQI) (Bajaj and Singh 2020). The classification of power quality enhancement approaches is shown in Figure (3).

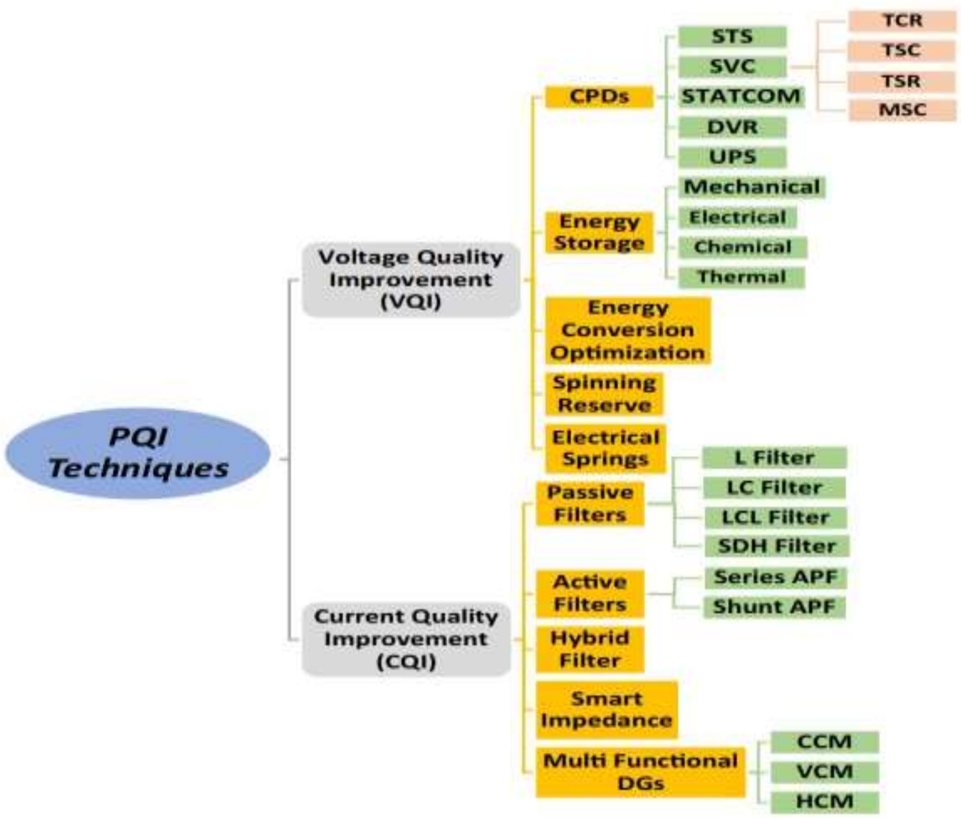


Figure 3. Classification of power quality improvement techniques (Bajaj and Singh 2020)

3.1. Voltage Quality Improvement Devices

Custom Power Devices (CPs), energy storage, energy optimization, spinning reserve, and electrical springs are the major types of voltage quality enhancement devices that may be utilized to increase power quality.

1) **Custom power devices (CPDs)** are complex devices used in power systems to protect sensitive loads from power quality issues such as voltage sag, swell, and THD. The CPDs' working principle is based on reactive power injection and voltage improvement. As a result, a comprehensive study is required to appreciate the dynamic behavior of CPDs under various scenarios in order to pick an appropriate device during system planning depending on technical and economic considerations and justifications (Farhoodnea, Mohamed, and Shareef 2014). The followings are the primary categories of CPDs:
2) **Solid-state Transfer Switch (STS):** Two operating scenarios of (STS) may be customized to supply the best power from the two sources to the load demand based on the two states of the thyristor (On and off). The STS is often utilized to limit voltage sags and interruptions to less than half cycles for most situations by moving the loads from the affected feeder/transmission line to a backup feeder/transmission. STS has a lightning-fast response time (Kantaria and Joshi 2008).
3) **Static Var Compensator (SVC):** one of the most important types of the FACTs devices is SVC, which can control the voltage of the weak buses in the system by inject the reactive power. When the voltage goes down the reactive power will injected to the grid from the shunt capacitor which controlled by thyristors, while when the voltage increased suddenly in the system, the reactive power should be absorbed by the reactors. SVC normally used in to improve the power quality during transient response (Sujatha and Anita 2015).
4) **STATic synchronous COMpensator (STATCOM):** is one of the custom power devices that may be used to control voltage variations caused by inrush current when it connected in parallel to the system, as well as reduce current harmonic distortions. The needed power for resolving power quality issues should be given directly from DC energy storage (Kantaria and Joshi 2008).
5) **Dynamic Voltage Restorer (DVR)**: In order to maintain the load voltage as steady as practicable, the DVR is a device that is linked to the power grid on the distribution side through a series transformer with the load. At the inverter's output, a passive filter is utilized to filter out harmonics of high orders. The voltage source inverter compensates the active power to the load using the storage device (Bajaj and Singh 2020).
6) **Uninterruptible power supply (UPS)**: When the main power source is unavailable, the UPS's primary function is to meet load demands from the storage system. There are three different sorts of UPSs: online, line interactive, and offline. Topological choices may be made based on efficiency, cost, and transfer time depending on the load requirement necessary. Furthermore, because batteries leak and need to be replaced every 5 years, UPSs require a high level of maintenance (Bajaj and Singh 2020).
7) **Energy Storage Systems (ESS):** because they can control the quantity of electricity pumped into the system, ESS has emerged as a potential solution to power quality concerns. Batteries, supercapacitors, fuel cells, and distribution generators (DG) such as wind turbines, PV solar systems, and diesel generators, among others, are examples of ESS that may be used in a power system. ESS of varying capacities is linked to the power grid to improve power quality. Connecting ESS to power grids has several benefits, many of which may be quite helpful to system operators and controllers (Nieto, Vita, and Maris 2016).
8) **Energy Conversion Optimization:** Many power quality problems, such as THD and power fluctuation, can arise during the energy conversion process, such as for wind energy conversion systems (WECS). In this situation, a suitable control circuit for the

side-grid converter is necessary. The Permanent Magnet Generator Side Frequency Converter may be controlled using rotor flow-oriented and direct torque control (DTC) control methods for wind turbine applications (PMSG). There is several different control strategies for peripheral converters, most of them are based on voltage-oriented control (VOC) or direct power control (DPC). The current control strategy is frequently what determines how successful a VOC-based control system is (Bajaj and Singh 2020).

9) **Spinning Reserve:** it can be described as the underutilized capacity that can be activated when the system operator's discretion. It is a valuable resource that may protect a power system against load loss in the event of a sudden outage of generating units, transmission and/or distribution network infrastructure, or a rapid rise in loads (Wang and Gooi 2011).

10) **Electrical Springs:** In the context of intermittent and unpredictable renewable energy sources, an electrical spring can manage both active and reactive power, allowing voltage regulation as well as power quality improvement. An electrical spring is interconnected in series with a portion of the total load and functions as a smart load, dampening grid oscillations by providing voltage management. Compared to previous demand-side management and energy storage methods, this methodology provides a significant advantage (Solanki and Joshi 2017).

3.2. Current Quality Improvement Devices

The main types of current quality improvement devices that can be used to improve the power quality which are: Passive Filters, Active Filters, Hybrid Filter, Smart Impedance and Multi-Functional DGs.

Passive Filters: because of non-linear loads, electrical networks now contain significant harmonic components that need to minimize as possible to restrict their impact. These harmonic components should be reduced at a particular level specified in relevant standards. Passive harmonic filters are the most efficient ways to get rid of harmonic components. The basic operating idea of a passive harmonic filter is to remove harmonic components by utilizing the filter's inductance and capacitance resonance occurrences. Figure (4) depicts a variety of filter types used to remove harmonic components from electrical power systems (Arikan, Kekezoğlu, and Fadıl Kumru 2016).

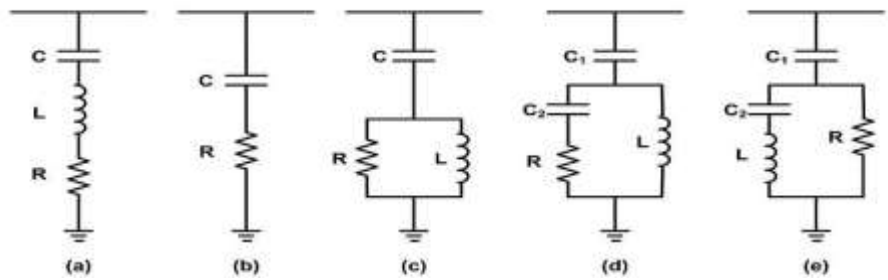


Figure 4. Passive filters Types: (a) single-tuned, (b) 1st order damped, (c) 2nd order damped, (d) 3rd order damped, (e) C-type.

Passive filters can be connected with inverters to reduce the harmonics in term of using the renewable energies, and it can be classified into three types in general: L-Filters, LC-Filters, and LCL-Filters, for each type have certain properties. Based on these features, can choose the type of the filter Figure (5) shows the three types of filters. L-filter is consists of single series inductor and it’s designed for low power while LC and LCL filters are designed for high power. The LC-filter is widely used because of simplicity and low cost, the idea of design a LC filter instead of LCL filter in this work is to overcome the problems which related with the high cost and more space required for LCL due two inductors that used (Kim et al. 2012).

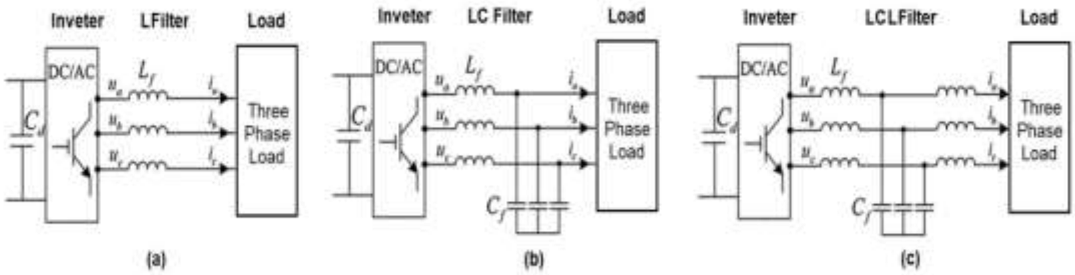


Figure 5. Types of passive filter grid connected (a) L-Filter (b) LC-Filter (c) LCL-Filter

1) **Active Filters:** are distinguished by the fact that they serve as a regulated current or voltage source. As a result, there are two primary types of active power filter systems: a parallel system that acts as an injected current source and a series system that acts as a voltage source. The waveforms of the produced currents or voltages diminish the negative components (e.g., higher harmonics) in the network currents and voltages in both circumstances. Filter current i_f is formed in such a way that the i_s grid current waveform has no unwanted components. Such a system, depending on the configuration and control method, can perform the following functions: reduce the harmonics, compensate the reactive power and balance the load (Buła, Grabowski, and Maciążek 2022).
2) **Hybrid Filters:** in comparison to passive and active filters, hybrid filters give higher efficiency and cost-effective options. Hybrid filters have utilized a variety of extraction and estimation procedures. Passive elements with one or more voltage-source inverters make up hybrid filters. These hybrid filters are more effective at reducing harmonics than pure active filters, particularly in high applications(Das, Ray, and Mohanty 2017).
3) **Smart Impedance: s**mart impedance is new technology that can be used to reduce the selective harmonics. The work procedure is like the hybrid active power filter, the output voltage can be controlled by the shunt active impedance and in same time work as harmonic eliminations. In this method the order of which need to omit can be selected during filter design process (Gonzatti et al. 2013).
4) **Multi-Functional Diesel Generators (DG):** the use of DGs in electricity distribution has several advantages such as: Peak load reduction, increased system security and dependability; improved voltage stability, grid strengthening, decreased costs, and system losses reduction. Although the use of DGs is raised using interfacing power electronics converters, but totally the DG can improve the power continuity and voltage stability.

4. Simulation And Results

The proposed system of this study is a sector of Iraqi power grid 132 kV side which is located in the north of Iraq (Mosul Gov.), the system consist from seven 132 kV station, two of them are generation station and the others are substation. Figure (6) shows the single line diagram of the proposed system. The non-linear load is connected to Hamam Al-aleel substation; the geographical area around this substation is fully with large-scale factories.

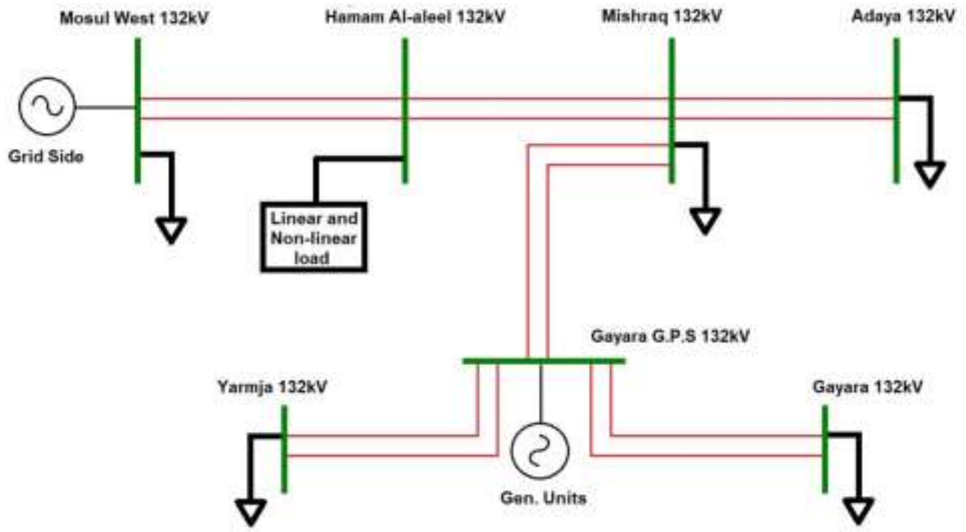


Figure 6. The Single line diagram of the proposed system

To insure the system is work properly, the load flow analysis is taken into consideration. By using MATLAB Simulink program, the result it can be given as in Figure (7). The results are compared with the actual readings from the Ministry of Electricity and it close to it.

Model Units Help

Model: Loadflow_2021a Update — The load flow converged! The table shows the load flow solution. Click Apply to update the model with this solution. Compute Apply Add bus blocks Report

	Block name	Block type	Bus type	Bus ID	Vbase (kV)	Vref (pu)	Vangle (deg)	P (MW)	Q (Mvar)	Qmin (Mvar)	Qmax (Mvar)	V_LF (pu)	Vangle_LF (deg)	P_LF (MW)	Q_LF (MVA)
1	Three-Phase Source	Vsrc	PV	BUS_1	132.0000	1.0200	0	150.0000	0	-100.0000	100.0000	1.0200	0.1700	150.0000	42.6906
2	Three-Phase Series RLC Load3	RLC load	PQ	BUS_2	132.0000	1.0000	0	21.0000	8.0000	-Inf	Inf	1.0198	0.1530	21.0000	8.0000
3	Three-Phase Series RLC Load	RLC load	PQ	BUS_3	132.0000	1.0000	0	85.0000	25.5000	-Inf	Inf	1.0136	0.1277	85.0000	25.5000
4	Three-Phase Series RLC Load1	RLC load	PQ	BUS_4	132.0000	1.0000	0	27.0000	9.0000	-Inf	Inf	1.0195	0.1195	27.0000	9.0000
5	Three-Phase Source1	Vsrc	swing	BUS_5	132.0000	1.0200	0	0.0100	0	-Inf	Inf	1.0200	0	249.4476	89.6859
6	Three-Phase Series RLC Load5	RLC load	PQ	BUS_7	132.0000	1.0000	0	170.0000	55.0000	-Inf	Inf	1.0194	-0.0681	170.0000	55.0000
7	Three-Phase Series RLC Load4	RLC load	PQ	BUS_6	132.0000	1.0000	0	95.0000	31.5000	-Inf	Inf	1.0200	-0.0020	95.0000	31.5000

Figure 7. Load Flow result of the proposed system

The implementations of the proposed system using MATLAB Simulink program it given in Figure (8).

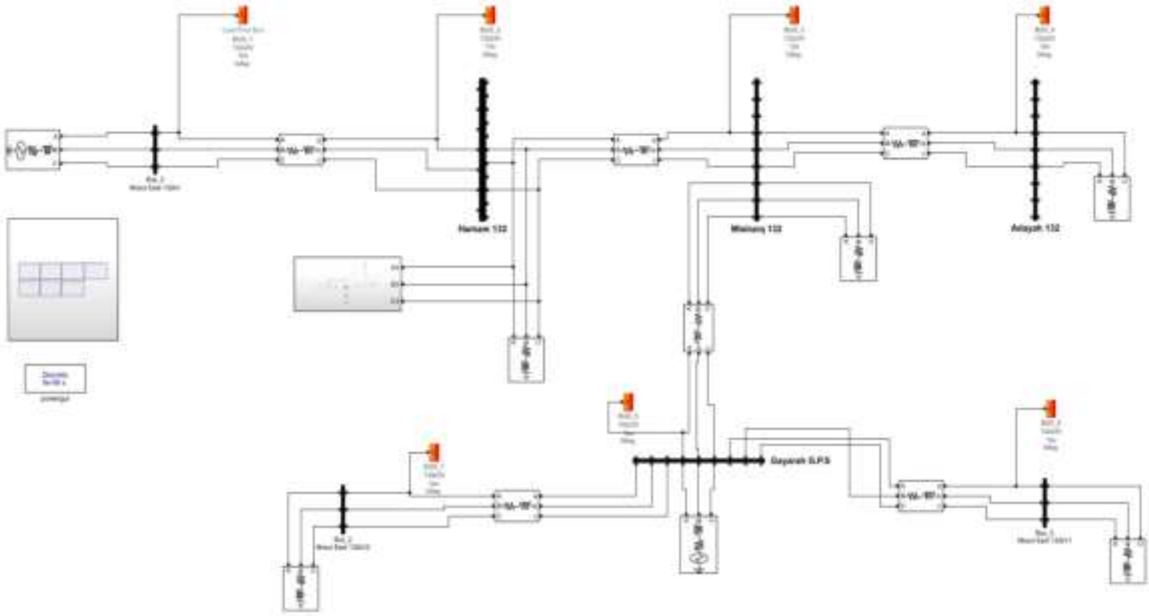


Figure 8. The Proposed system using MATLAB Simulink Program

The detailed load of each substation it given in Table (1).

Table 1. Load of the substations

<table>
<tr><th>Substation name</th><th>Voltage (kV)</th><th>Active Load (MW)</th><th>Reactive Load (MVAR)</th></tr>
<tr><td>Mosul West</td><td>132</td><td colspan="2">Generation Side</td></tr>
<tr><td rowspan="2">Hamam Al-aleel</td><td rowspan="2">132</td><td>12.5</td><td>8</td></tr>
<tr><td colspan="2">50 (non-linear load)</td></tr>
<tr><td>Mishraq</td><td>132</td><td>85.5</td><td>28.5</td></tr>
<tr><td>Adaya</td><td>132</td><td>27</td><td>9</td></tr>
<tr><td>Gayara G.P.S</td><td>132</td><td colspan="2">Generation Side</td></tr>
<tr><td>Gayara</td><td>132</td><td>95</td><td>31.5</td></tr>
<tr><td>Yarmja</td><td>132</td><td>170</td><td>55</td></tr>
</table>

The non-linear load it located in the Hamam Al-aleel substation and it consist from three phase rectifier as shown in Figure (9). The harmonics that produced by the non-linear load can be reduced by the passive filters, the suggested one it connect to the grid after 0.5 sec of the simulation time, that's mean the result and the waveforms from t=0 to t=0.5sec are achieved without passive filter, while the result from t=0.5sec to t=1 sec are with passive filter and it clear, the harmonics and distortion are reduced.

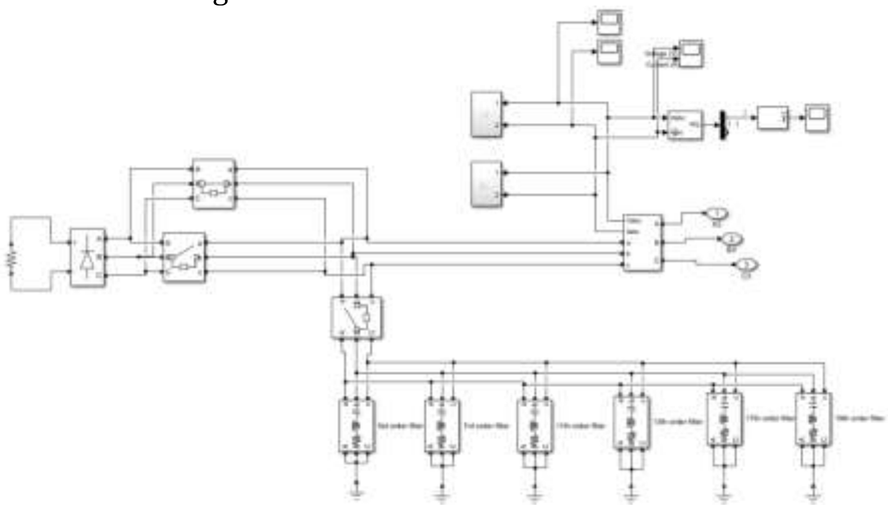


Figure 9. The Non-linear load with passive filters

This filter's development is built on three parameters: the harmonic current order that has to be blocked, the capacitive reactive power that it will supply, and its quality factor. It is adjusted to suppress a single frequency. During the design phase, the fundamental frequency and voltage level provided by the system must also be taken into account. In conclusion, the following values are utilized to define the input parameters:

h	Represent the harmonic order
Qc	Represent the reactive power passed through of the filter in [MVAr]
Q	Represent the quality factor
f	Represent the frequency of the system in [Hz]
V	Represent the voltage of the system in [kV]

The quality factor, which in this instance is defined as the ratio between the filter's reactance and resistance, is a number that determines the bandwidth of the filter. The filter may be designed using the equations below (Arikan et al. 2016):

$$C = \frac{Q_c}{2\pi\, f\, V^2} \tag{1}$$

$$X = \frac{1}{2\pi\ f\ hC} = \sqrt{\frac{L}{C}} \quad (1)$$

$$L = \frac{X}{2\ f\ h} \quad (1)$$

$$Q = \frac{2\pi f L}{R} \quad (1)$$

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

Where, X is the reactance of the inductor or the capacitor at the tuned frequency.
The fundamental harmonic filter components of the proposed system it can be listed as:
Qc = 40 MVAR, V = 132 kV and f = 50 Hz,
$Qc = V^2/Xc$
$Xc = (132000)^2/(40*10^6) = 435.6\ \Omega$
$C = 1/\ (2*\pi*f*Xc) = 7.311*10^{-6}$ F
Table (2) shows the values of parameters as calculated for all six order filters.

Table 2. Parameters of the fixed passive shunt filters

Harmonic Order	Inductance L (H)	Capacitance C (F)	Resistance R (Ω)
5th	0.0555	$7.311*10^{-6}$	1.742
7th	0.0283	$7.311*10^{-6}$	1.244
11th	0.011	$7.311*10^{-6}$	0.792
13th	$8.2*10^{-3}$	$7.311*10^{-6}$	0.67
17th	$4.8*10^{-3}$	$7.311*10^{-6}$	0.512
19th	$3.84*10^{-3}$	$7.311*10^{-6}$	0.4585

The Total Harmonics Distortion (THD) of the voltage waveform at Hamam Al-aleel substation before adding passive filter (t=0 to 0.5 sec) it (1.58%) and it can be given in Figure (10).

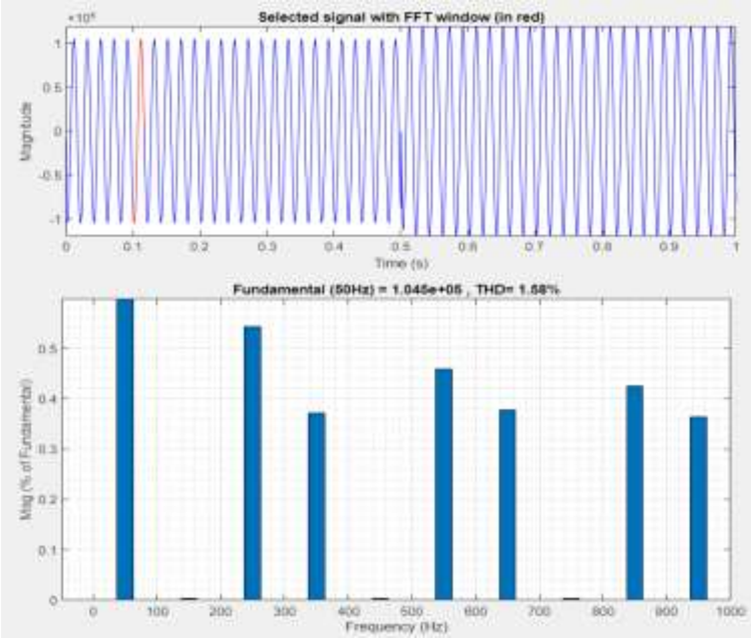


Figure 10. THD of the voltage waveform at Hamam Al-aleel substation before passive filters filter

The Total Harmonics Distortion (THD) of the voltage waveform at Hamam Al-aleel substation after adding the passive (t=0.5 to 1 sec) it (0.32%) and it can be given in Figure (11).

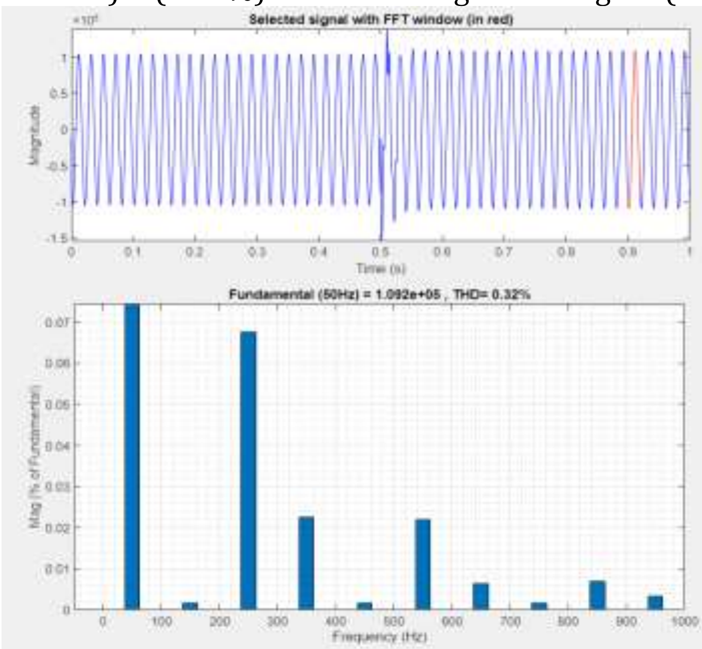
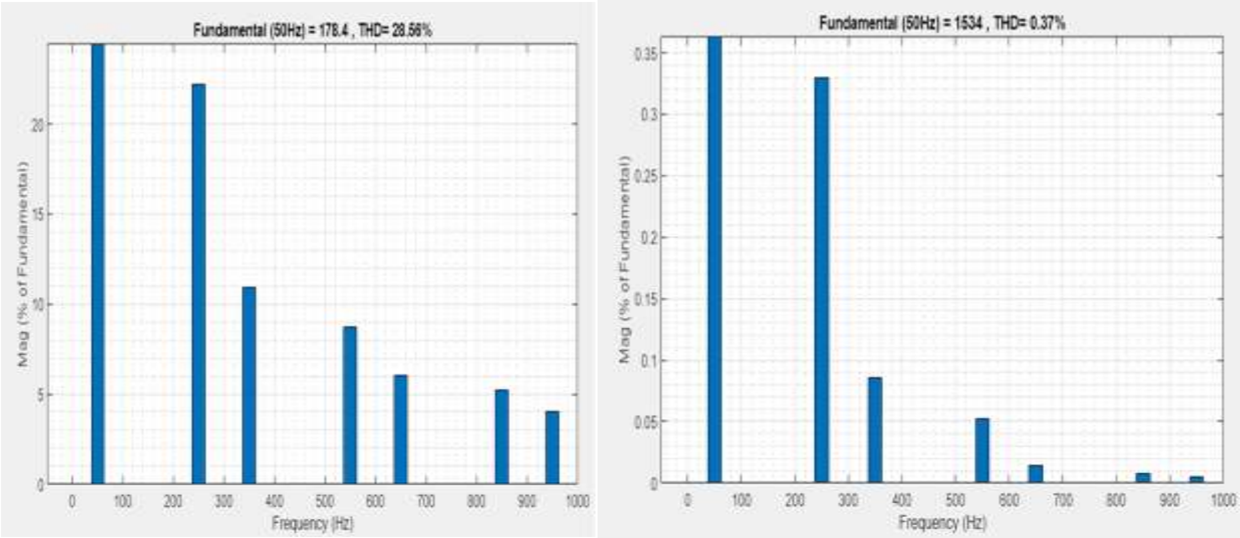


Figure 11. THD of the voltage waveform at Hamam Al-aleel substation after passive filter

It clear the THD are reduced by using the proper passive filter. The Total Harmonics Distortion (THD) of the current waveform at Hamam Al-aleel substation before and after the passive filters is given in Figures (12 –a,b) respectively.



(a) (b)

Figure 12. (a) THD of the current waveform at Hamam Al-aleel substation before passive filter, (b) after adding the passive filter .

The three phase current before adding the passive filters at Hamam Al-aleel substation is shown in Figure (13).

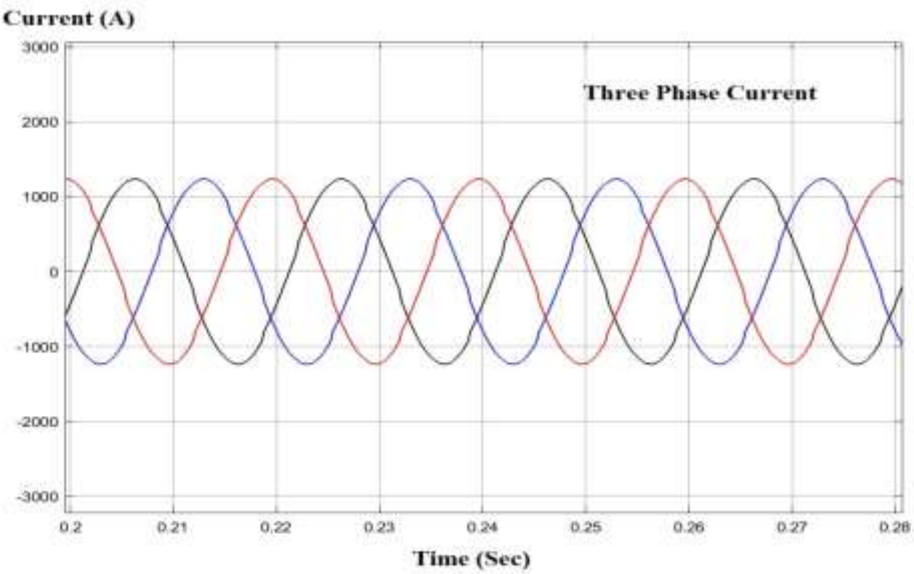


Figure 13. Three Phase current before adding passive filters at Hamam Al-aleel substation

The three phase current after adding the passive filters at Hamam Al-aleel substation is shown in Figure (14), it clear the distortion in the current waveforms is reduced when the filters applied.

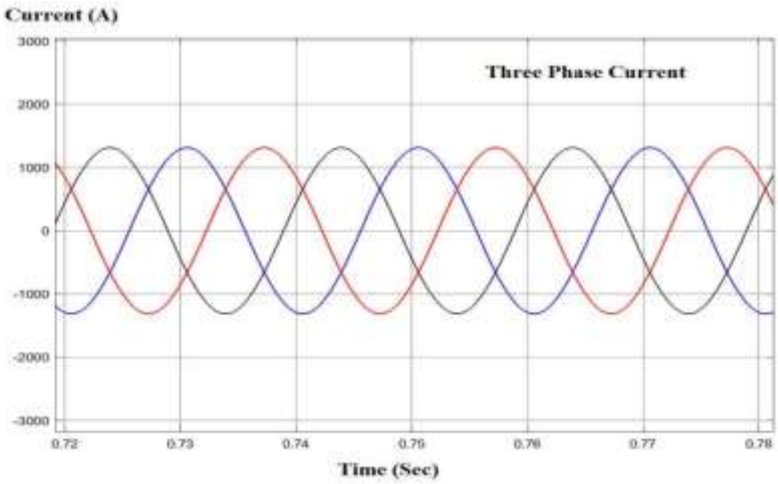
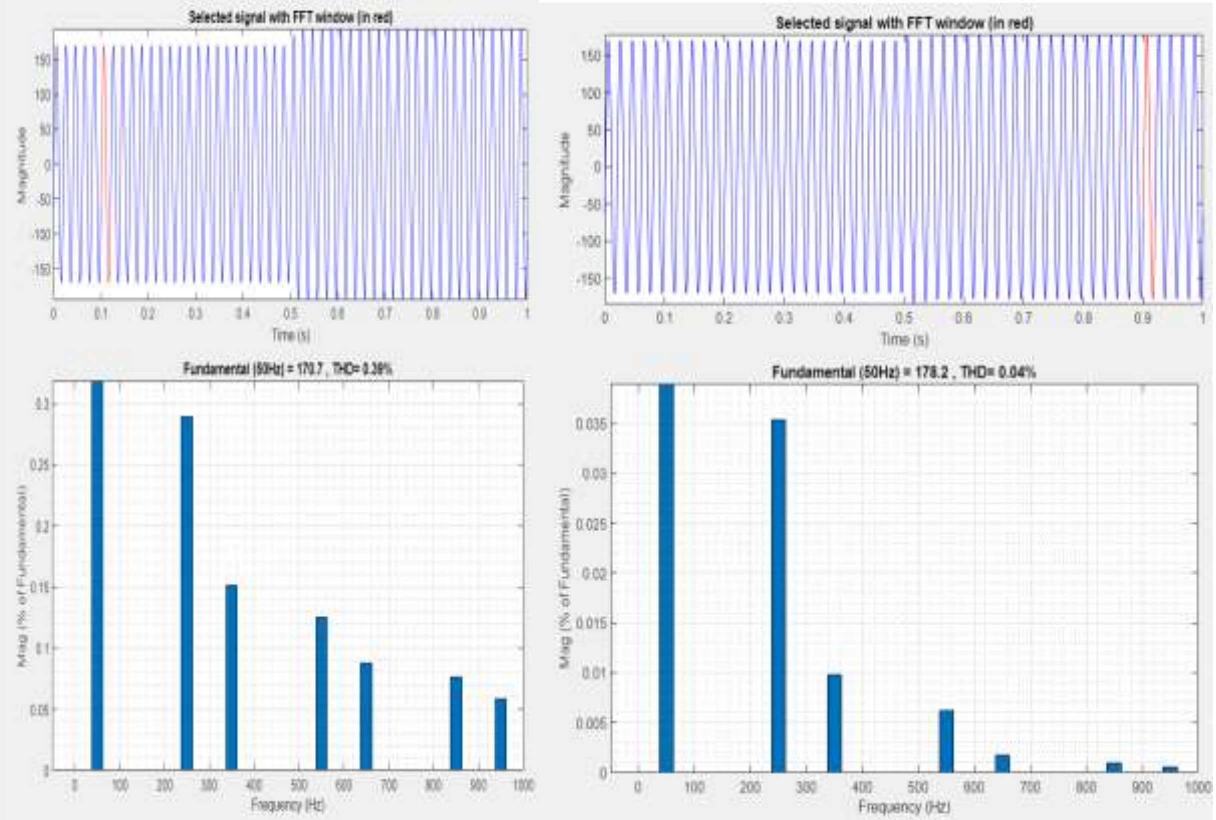


Figure 14. Three Phase current after adding passive filters at Hamam Al-aleel substation

It clear from the figures above the THD in the current waveforms is greater than the voltage waveforms and it can be reduced from 28.5% to 0.37%. The Figures (15) (a, b) shows the THD in current waveform of the Mishraq substation.



(a) (b)

Figure 15. (a) THD of the current waveform at Mishraq substation before passive filter, (b) after adding the passive filter

The three phase voltage and current of the non-linear load at Hamam Al-aleel substation 132 kV is shown in Figure (16). The THD reduced from 0.34% to 0.04% at Mishraq substation.

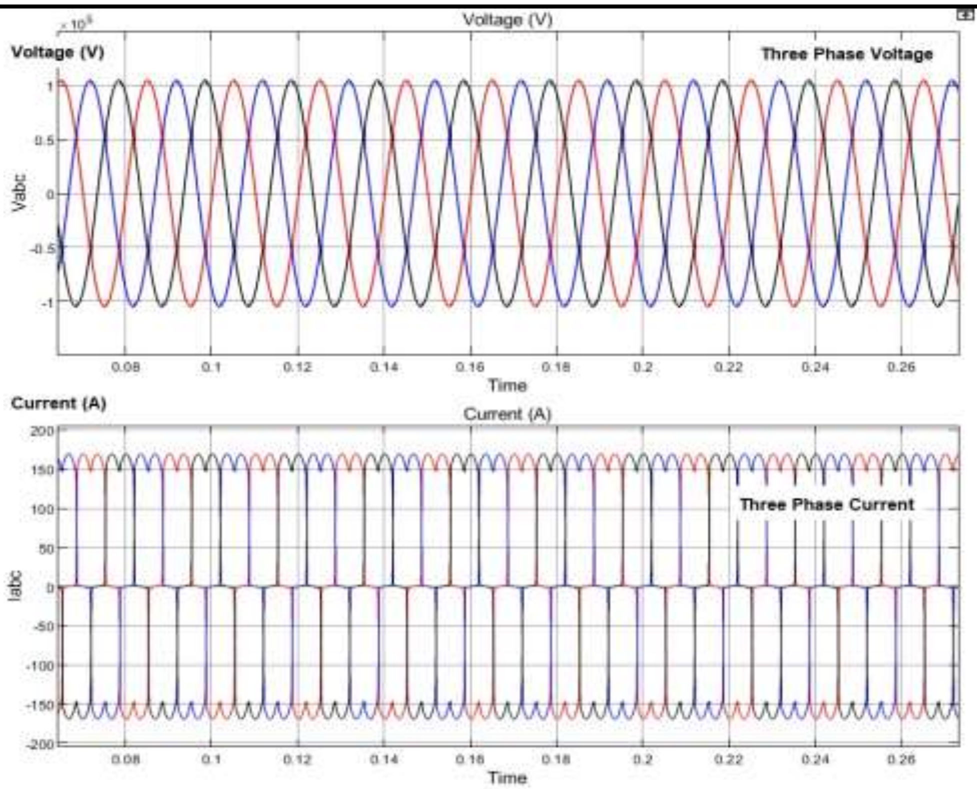


Figure 16. Three Phase voltage and current of the non-linear load

It clear from the Figure (15) when the measured records are taken from the far substation the THD is reduced.

Table (3) shows the comparison between the results achieved of the THD by using two different methods for suppression the harmonics which are LC filters and passive individual filters, the results show that the THD is reduced by using the second method.

Table 3. Comparison between the THD by LC and harmonic order filters

Name of substation	THD with LC filter	5^{th} Harmonic order	7^{th} Harmonic order	THD with 5,7,11,13,17 and 19^{th} harmonic order filters	5^{th} Harmonic order	7^{th} Harmonic order
Hamam al-aleel	0.92%	0.91%	0.15%	0.37%	0.33%	0.085%
Mishraq	0.79%	0.79%	0.105%	0.04%	0.036%	0.0098%
Addayah	0.23%	0.23%	0.05%	0.04%	0.0355%	0.01%

5. Conclusion

Problems with harmonics in power quality are more severe than transient occurrences that last for a brief period, like lighting or voltage sags. Harmonics are periodic steady-state events that continuously alter the voltage and current waveforms. When more than one nonlinear load is coupled to a system, the harmonics issues might worsen. To preserve the power system source and the electrical devices, such distortion should be avoided. Here in this study, we show the effect of the non-linear load in the Hamam Al-aleel substation on the Iraqi power system quality, the THD is increased rapidly at the Hamam Al-aleel substation and the current waveform is more affected when compared with the voltage waveform. To reduce the THD, active or passive filters are proposed. In this work two methods are used to suppress the THD which are LC, and passive individual filters to eliminate 5^{th}, 7^{th}, 11^{th}, 13^{th}, 17^{th} and 19^{th} harmonic orders. The THD of the current wave is reduced from 28.53% to 1.58% it's within the IEEE standards-519 for the system above the 69kV. The non-linear load is also the effect of the other substations, but the affect is less than that of the Hamam Al-aleel substation

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