UNVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

ANALYSIS AND MITIGATION OF HARMONICS IN POWER DISTRIBUTION NETWORKS CONTAINING CAPACITOR BANKS

MASTER THESIS

Omar Sagban Taghi AL-BUTTI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OFMASTER OF SCIENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING

NOVEMBER 2017

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Supervisor: Prof. Dr. Doğan ÇALIKOĞLU

Omar Sagban Taghi AL-BUTTI, having student number 1406030027 and enrolled in the Master Program at the Institute of Science and Technology at the University of Turkish Aeronautical Association, after meeting all of the required conditions contained in the related regulations, has successfully accomplished, in front of the jury, the presentation of the thesis prepared with the title of: "Analysis and Mitigation of Harmonics in Power Distribution Networks Containing Capacitor Banks".

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Thesis Defense Date: 29 November 2017

UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUE OF SCIENCE AND TECHNOLOGY

I hereby declare that all the information in this study I presented as my Master's Thesis, called: “Analysis and Mitigation of Harmonics in Power Distribution Networks Containing Capacitor Banks” has been present in accordance with the academic rules and ethical conduct. I also declare and certify with my honor that I have fully cited and referenced all the sources I made use of in this present study.

23.11. 2017

Omar Sagban Taghi AL-BUTTI

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In the name of Almighty Allah, the most Gracious and the most Merciful All the praises are for Him alone.

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November 2017 Omar Sagban Taghi AL-BUTTI

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LIST OF ABBREVIATIONS

VFD	:	Variable frequency drive
ASD	:	Adjustable speed drive
FACTS	:	Flexible Alternating Current Transmission System
AF	:	Active filter
PF	:	Passive filter
STR	:	Single tuned filter
DTF	:	Double tuned filter
RF	:	Reactance filter
PSO	:	Particle swarm optimization
THDv	:	Total harmonic distortion voltage
THDi	:	Total harmonic distortion current
AC	:	Alternating current
DC	:	Direct current
UPS	:	Uninterrupted power supplies
PV	:	Photo voltaic
MPPT	:	Maximum power point tracking
ACA	:	Ant colony algorithm
GSA	:	Gravitation search algorithm
BSA	:	Backtracking search algorithm
AI	:	Intelligent algorithm
ANN	:	Artificial neural network
FLC	:	Fuzzy logic control
ANFIS	:	Adaptive neuro-fuzzy system

ABSTRACT

ANALYSIS AND MITIGATION OF HARMONICS IN POWE DISTRIBUTION NETWORKS CONTAINING CAPACITOR BANKS

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Harmonics in electric power systems, are produced due to the existence of non-linear electric loads. Recently, the increase in use of non-linear loads such as in fluorescent Lamps, switching control with semiconductors and other power electronic devices such as flexible AC transmission line system (FACTS), has led to the increase in harmonics distortion level of the current and voltage waveforms, increase in power loss and decrease in the power factor of the power system. Many passive filters are used in the distribution systems to minimize the harmonics existence in the voltage and current waveforms. These filters have many advantages such as their designs are simple, easy structures and low costs. Therefore, they are good and fast in terms of response because they consist of resistors, inductors, capacitors and they do not require external sources. However, these filters have limited standard sizes and their power settings need to be adjusted so they can carry out their job efficiently.

In this thesis, the particle swarm optimization (PSO) algorithm has been used to find the optimum values for the power filter components. The filters used in this thesis were single tuned filter (STF), double tuned filter (DTF) and reactance filter (RF). The objective considers the total harmonics distortion (THD) for voltage and current of the distribution system. PSO-based passive filters were applied to the actual distribution systems (the Iraqi-Hai Tunis distribution system). Two adjustable speed drives represented the non-linear load to generate the harmonics in the distribution system.

The system was implemented using MATLAB/Simulink and m-file code. Simulation results have achieved good performance and minimized the harmonics distortion for voltage and current waveforms. It also improved the power factor in the distribution systems.

Keywords: Distribution networks, passive filter, harmonics, particle swarm optimization (PSO) algorithm, MATLAB/Simulink.

ÖZET

KAPASİTÖR BLOKLARI BULUNAN GÜÇ DAĞITI AĞLARINDA HARMONİKLERİN ANALİZİ VE AZALTILMAS

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Elektrik enerjisi sistemlerinde harmonikler, doğrusal olmayan elektrik yüklerinin varlığına bağlı olarak üretilmektedir. Son zamanlarda, floresan lambalar, yarıiletkenlerle ve esnek AC iletim hattı sistemi (FACTS) gibi diğer güç elektronik cihazlarıyla anahtarlama kontrolü, gibi yarı iletkenlerin kullanımındaki artış, akım ve voltaj dalga formlarının harmonik bozulma seviyesinin yükselmesine, güç kaybının artmasına ve güç sisteminin güç faktöründe azalmaya neden olmaktadır. Gerilim ve akım dalga formlarındaki harmonikleri minimuma indirmek için dağıtım sistemlerinde birçok pasif filtre kullanılmaktadır. Bu filtreler, tasarımları basit olması, basit yapıları ve düşük maliyetleri gibi birçok avantaja sahiptir. Bu nedenle, tepki açısından iyi ve hızlıdırlar çünkü dirençler, indüktörler, kapasitörlerden oluşmakta ve dış kaynaklara ihtiyaç duymamaktadıklar. Bununla birlikte, bu filtrelerin sınırlı standart boyutları vardır ve güç ayarlarını, işlerini etkili bir şekilde yerine getirebilecek şekilde ayarlamaları gerekir.

Bu tezde, güç filtresi bileşenleri için optimum değerleri bulmak için Parçacık Sürü Optimizasyonu ((PSO) algoritması kullanılmıştır. Bu tezde kullanılan filtreler tek ayarlı filtre (STF), çift ayarlı filtre (DTF) ve reaktans filtresi (RF) idi. Amaç, dağıtım sisteminin voltajı ve akımı için toplam harmonik bozulmasını (THD) dikkate almaktadır. Gerçek dağıtım sistemlerine (Irak-Hai Tunis dağıtım sistemi) PSO tabanlı pasif filtreler uygulanmıştır. İki ayarlanabilir hız sürücüsü, dağıtım sisteminde harmonikleri oluşturmak için doğrusal olmayan yükü temsil etmiştir. Sistem, MATLAB / Simulink ve m-dosya kodu kullanılarak uygulanmıştır. Simülasyon sonuçları, iyi performans sağlamış ve voltaj ve akım dalga formları için harmonik bozulmalarını en aza indirmiştir. Aynı zamanda dağıtım sistemindeki güç faktörünü de geliştirmiştir.

Anahtar Kelimeler: Dağıtım şebekeleri, pasif filtre, harmonikler, parçacık sürüsü optimizasyonu (PSO) algoritması, MATLAB /Simulink

CHAPTER ONE

INTRODUCTION

1.1 Presentation of the Work

In this work, we have studied the effect of connecting 400 KVA nonlinear loads to an 11Kv feeder, in distribution grid of Baghdad. The nonlinear loads increased the distortion in the voltage and current waveforms which lead to the occurrence of harmonics in the voltage and current waveforms. This in turn, introduced problems to the electric power systems such as increasing the electrical losses, reducing the power factor, and overloading.these are effects which cause failure of equipment [1, 2]. Various passive filters (single tuned filter, double filter, reactive filter) have been used to mitigate the harmonics. The double tuned filter is found to be the most effective one for our case.

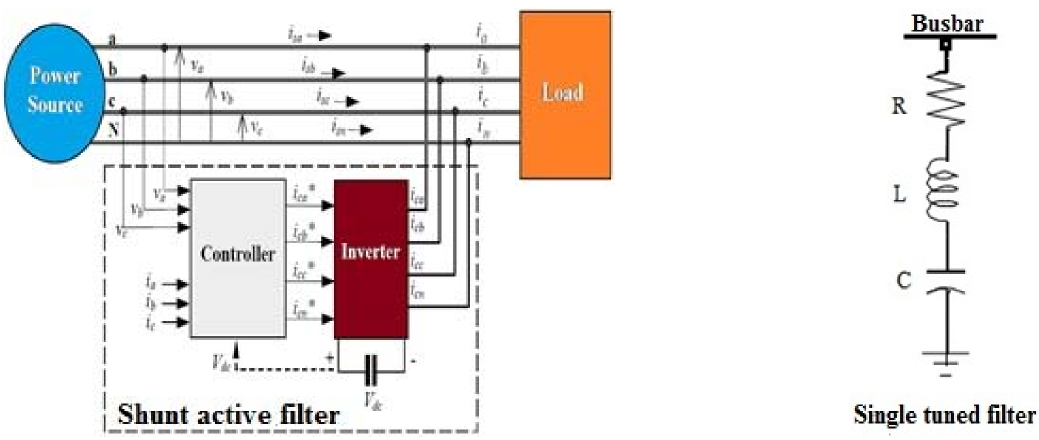
The electrical power in Iraq faces shortage in generating electrical power and also overloading, especially in summer due to increased demand for electrical power. This leads to decrease in voltage level and efficiency of power distribution lines. The conventional way to solve this is by using a shunt capacitor in the electrical system, which adds capacitive loads (KVAR) to compensate part of the inductive loads. Thus, the power factor and efficiency of transmission lines will be improved, and equipment failure is minimized [3]. However, the shunt capacitor cannot resolve all these issues, since harmonics will still be present.The impedance of a capacitor decreases when the frequency increases ($Z = 1/j\omega c$). Non-linear devices draw current at the frequency of 50 Hz and inject current back into the grid at a higher frequency. Harmonic currents can cause more heating in cables, transformers and motors because the resistance of the cable increases with frequency. Also harmonic voltages distort the voltage waveform [1, 10].

In this study, the passive filter was applied to minimize the effect of the non-linear loads in the distribution system of Baghdad, i.e. low harmonic distortion level. The particle swarm optimization (PSO) algorithm was used to find the best values for the power filter components, so it could function efficiently.

The results achieved showed a much better performance, low harmonics distortion level for voltage and current waveforms and also improve the power factor in the distribution systems.

1.2 Passive Filter

In recent years, many techniques have been used to minimize the harmonics distortion level in the electric power system through designing filters into the electrical power system such as active filter (AF) and passive filter (PF) [6, 15]. The elimination or mitigation of harmonics can be accomplished through a variety of techniques [2]. The active filter is very beneficial, but it also has disadvantages, such as its design is complex and very expensive as shown in Figure 1.1a. The passive filter consists of resistors, inductors, and capacitors as shown in Figure 1.1b. The latter does not need to be connected to an external power supply and its design is simple. However, the setting and sizing of the components are not easy to achieve. Suitable power values are required within with the electric power system to minimize the harmonic and distortion of the voltage and current waveforms [11, 12]. In this study, a passive filter will be considered to solve the harmonics problem in the distribution system.



(a) (b)

Figure 1.1: Simple structure for filter (a) active, and (b) passive.

1.2.1 The Importance of Passive Filter

As mentioned above, the passive filter minimizes the harmonics distortion in the electric system, therefore, it is required in the distribution systems to reduce the harmonics produced due to the non-linear loads. A passive filter has many types such as single tuned filter, double tuned filter, reactance filter, etc. Moreover, it has numerous advantages, mainly its low cost in designing it, its simple structure and easy design since it doesn't require a supply voltage and electrical devices such as, transistors and operational amplifiers. It only needs electrical components, i.e. the resistor, inductor and capacitor [11, 24].

1.2.2 Types of Passive Filter

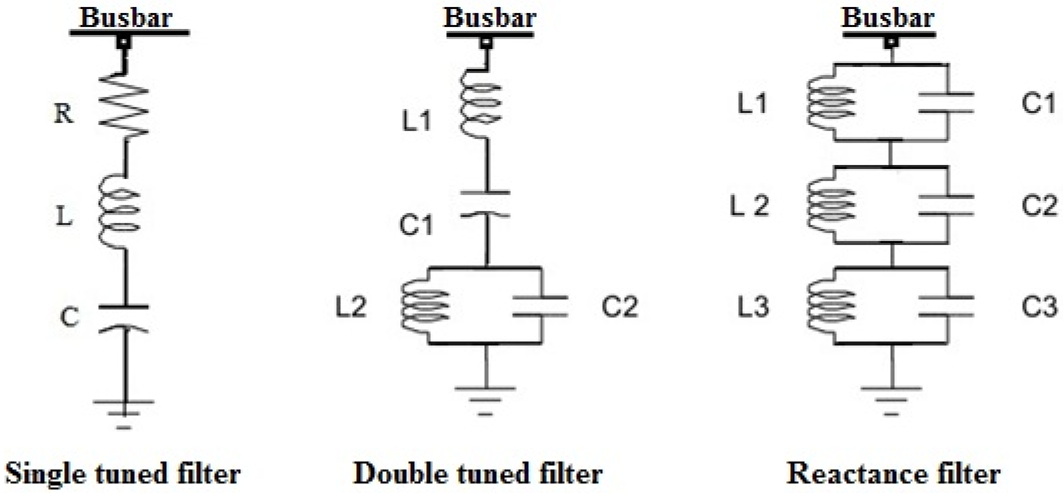
In this study, three types of a passive filter will be implemented.

a- The single tuned filter (STF), which is either a low pass or band pass filter. It is used in many applications because it's easy to design and also cheap as shown figure 2.1 (a).

b- The double tuned filter does the same job as two single tuned filters (STFs). It allows harmonics to get through if it's above the notch frequency (called high pass filter). At fundamental frequency, a higher rate of harmonics causes resistor loss as shown figure 2.1 (b).

c- Reactance filter (RF): Its design consists of (L and C) in parallel, the voltage and current harmonics are minimized by the reactance one-port compensator as shown figure 2.1 (c).

High harmonics in the electric power system are removed in the current and voltage waveforms by (STF) or double tuned filter (DTF), which can significantly help improve the system [28, 29].



(a) (b) (c)

Figure 1.2: Simple structure for filter (a) STF, (b) DTF,and (c) RF.

1.3 Literature Review

Numerous researchers have been studied about harmonics analysis in the power systems as shown below:

1. Hussam M. AL haj et al. [4] used active filter a common tool has been used for harmonic minimizing. This work presents proposed two algorithms to predict the real-time harmonics in the system, namely, the Least Mean Square and Recursive Least Square methods. The results are showed the Least Mean Square algorithm better results and good performance from the Recursive Least Square algorithm.
2. Rajendra B. Yadiki et al. [5] and Bhakti I. Chaughule et al. [6] suggest the three-phase inverter injected in the system to make imbalance system and harmonics generation. The researchers used the active filter to minimize the harmonics and make the balance system. The proposed system is implemented by MATLAB/SIMULINK.
3. M. Davudi [7] explained the harmonic distortion source in the power system network. The phase shifting transformers, harmonic minimizing and many filters are applied to reduce the harmonics in the power systems. Simulation has been used the Electromagnetic Transient Analysis Program (ETAP).
4. Nien-Che Yang et al. [8], proposed unbalanced radial distribution systems to solve this using three-phase harmonic power flow method. Moreover, the proposed method is applied the current injection technique. The proposed method is robust and reliable through it applied four IEEE tests feeder.

5. Aryan Kaushik et al. [10] used the passive filter on the five bus IEEE test to minimize the harmonics in the system. The system applied on the MI Power software. Moreover, this work explained the harmonic specifications such as harmonic factor, characteristic harmonic and non-characteristic harmonic.

6. Bruno Pires, and Paulo F. Ribeiro. [11] estimated the power system harmonics using the passive filter. The proposed passive filter is achieved good results for minimizing the harmonics and improve the power factor. MATLAB Simulink and SimPowerSystems used in the project.

7. C. Venkatesh et al. [12] used IEEE-13 bus IEEE distribution system to analysis the harmonics. The distribution system and variable speed drive implemented PSCAD/EMTDC software. The proposed system is used three different filters, namely, single Tuned filter, double tuned filter and reactance filter. The results filters are compared between them, and they were good results.

8. Ravi Kmur. [13] presented the analysis propagation harmonic in power electrical distribution system and used a novel passive filter for mitigation the voltage harmonics. The proposed system is implemented on the MATLAB/SIMULINK software package. The results were the effectiveness of optimal inductance placement on reactive power compensation, improve the voltage, minimizing the power losses and less costly.

9. Pooya Bagheri [14] used two methods to mitigate harmonics passive filter and active filter to minimize the harmonic distortion on the voltages and current in residential network feeders. The comparisons between two methods achieved in both sides technical and economic. This work was supported by different analytical and studies simulation and the result solved the problem increase harmonic in consumers' feeders.

10. Rooh U. Shaikh et al [24] analyzed and minimized of harmonics created by power electronic converters. This work used a passive filter to reduce the harmonic and waveform distortion. The investigated and calculated the harmonic by Fast Fourier Transform (FFT) to evaluate the Total Harmonic Distortion (THD) of the converters. The Proposed system was implemented by MATLAB/SIMULINK.

1.4 Singificance of the Work

Many researchers have tried to enhance the electric distribution system by minimizing the harmonics and distortions of the voltage and current waveforms, as well as improve the power factor to decrease the losses in the distribution system. Researchers used the shunt capacitors, active filters and passive filters to improve the electric distribution system through a variety of ways. It has been proved that the active filter is efficient, but again the problem is the complexity of its design and price. The passive filter is also efficient and fast in its response, because it consists of resistor, inductor and capacitor, and doesn't require external sources [6, 7, 15]. However, all filters require the correct sizing and the suitable power settings to carry out its job in the electric distribution system [4, 13, 14]. This requires time and effort to achieve positive results.

This research project aims to develop an optimal design for the single tuned filter, double tuned filter and reactance filter in the electric distribution system. The distribution system that has been used in this study is the Iraqi-Hai Tunis Distribution. The objectives of this research are described as follows:

1. To design and build the actual distribution system, which is Iraqi-Hai Tunis Distribution, using the MATLAB/SMULINK to simulate and modify the system itself. Moreover, the power flow is easier to measure in terms of the current, voltage, real power, reactive power and power factor.
2. To develop an optimal design of three filters, i.e. the single tuned filter, double tuned filter and reactance filter in the Iraqi-Hai Tunis Distribution, by using particle swarm optimization (PSO). The role of the proposed filter based PSO is to minimize the harmonics and distortion of voltage and current waveforms, and also enhance the power factor to reduce power loss.
3. To verify the proposed optimal PSO-based filter for electric distribution system through design and implementation on the Iraqi-Hai Tunis.

1.5 Organization of the Thesis

Chapter I discusses the research background to show the importance of filters in the electric distribution system. Also in this chapter, the introduction, problems, objectives and some literature reviews of researchers have been explained in detail. The final part of this chapter presents the scope of the research work.

Chapter II introduces the structure of the electric distribution system and presents the structures of all filter types. The description of the filters' design in the distribution system is the final part of Chapter II.

Chapter III presents the PSO algorithm. It also presents the structure and development of the PSO-based single tuned filter, the PSO-based double tuned filter and the PSO-based reactance filter. Finally, it presents the simulation model of Iraqi-Hai Tunis distributing system.

Chapter IV presents the optimization results for each filter. It also includes the results and the total harmonic distortion (THD) for voltage and current, as well as the power factor and active/reactive power.

Chapter V concludes all the work that has been done for this thesis, as well as suggestions for future work.

CHAPTER TWO

MODELING OF DISTRIBUTION NETWORK COMPONENTS

2.1 Introduction

This chapter introduces the basic concept of the components of a distribution system model. It also presents the main source of harmonics generated in distribution systems as well as an explanation of harmonic indices. Finally, this chapter presents the types of power system filters, namely active and passive filters.

2.2 Distribution System Components

Components of the distribution systems are needed to achieve accurate and meaningful results from the harmonics analysis. The model for the distribution system components includes generators, loads, lines and transformers [30]. A brief summary of some of these typical models is given below:

2.2.1 Generator Model

The generators are modeled as shown in Figure 2.1. If a generator is Y connected with a grounded neutral, then the model will be as shown as in Figure 2.1(a) in each sequence, except for the fact that the value of Yg will be different in each sequence [30].

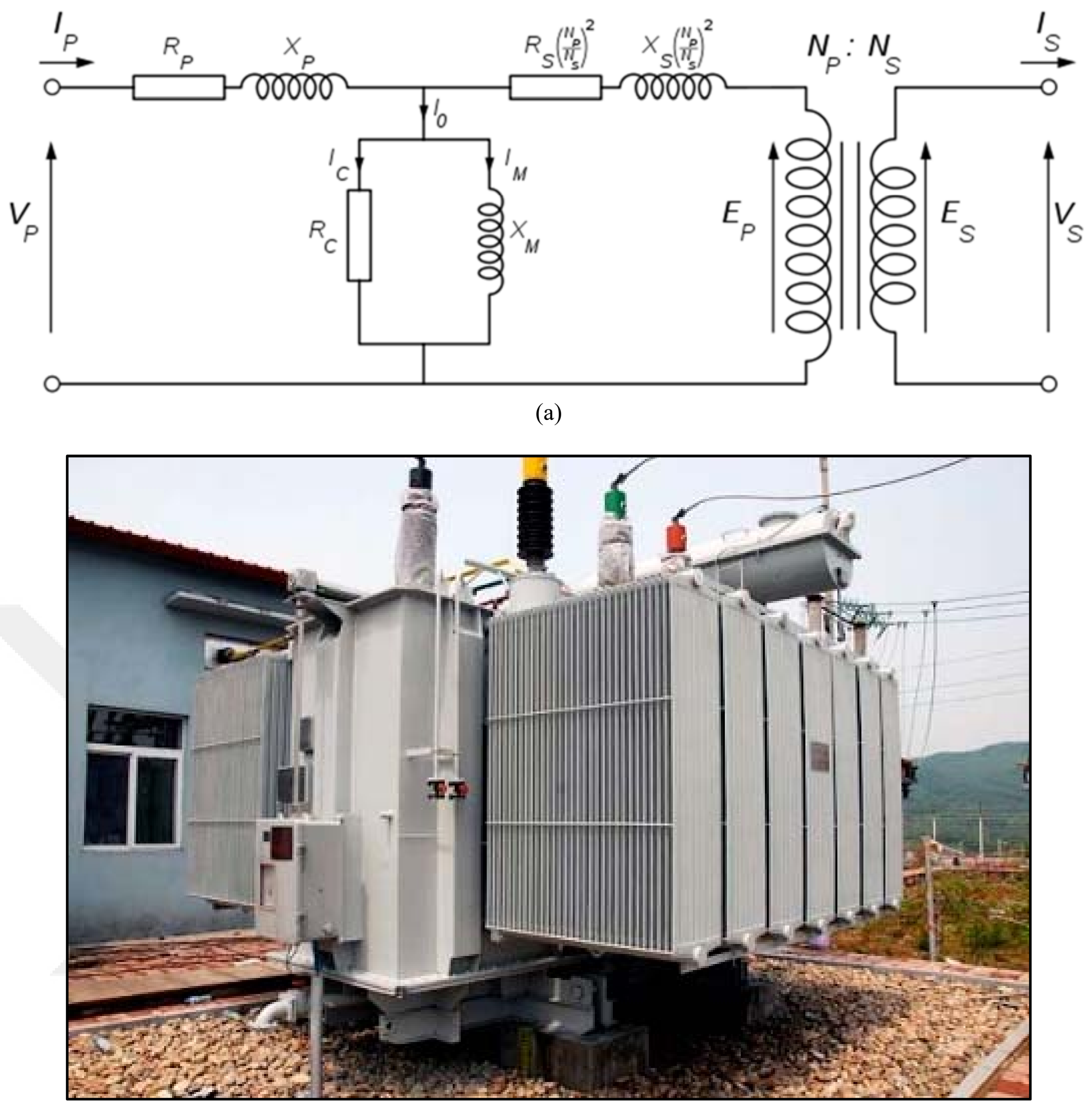
Electrical energy is generated in this station. Electricity generation is the procedure of transforming non-electrical energy into electricity. For electrical utilities, it is the first stage in delivering power to consumers. A generator usually has a large electromagnet spinning inside a stationary coil of wire. As the magnetic field produced by the ends of the magnet travels through the turns of wire in the stationary coil, an electric current is produced in the wire. Increasing the number of turns of wire in a ring or doughnut configuration increases the current in the wires [16]. Figure 2.1(b) shows a snapshot of the generators.

(a) (b)

Figure 2.1: Generator model (a) single line diagram, and (b) snapshot.

2.2.2 Transformer Model

There are two transformer types, namely step up and step down. On the generator side, a step-up transformer is used and on the distribution side, step-down transformers are used. For example, the Iraqi grid uses 11/132 kV step-up transformers on the generator side and 132/33 kV and 66/11 kV step-down transformers on the distribution side. Transformers are necessary to link parts of distribution systems that operate at different voltage levels. In addition to changing the voltage levels, transformers are also used to control voltage and are almost invariably equipped with taps on one or more windings to allow the ratio of the turn to be changed, as shown in Figure 2.2(a). Figure 2.2 (b) shows a snapshot of the high voltage transformer [16]:



(a)

(b)

Figure 2.2: Transformer model (a) single line diagram, and (b) snapshot.

2.2.3 Distribution Lines Model

A distribution line connects the high voltage side (transmission line) to the substations and the substations to the loads. An electrical distribution system is comprised of equipment which transmits generated power over short distances. Distribution lines connect power from the high voltage side (substation 1) to)substations 2)and then to the loads. These lines also run to other cities, or areas where consumption requirements are high. A distribution line ends when it reaches a distribution substation or a distribution substation [30]. The distribution lines are installed on towers or as underground cable, as shown in Figure 2.3.

(a)

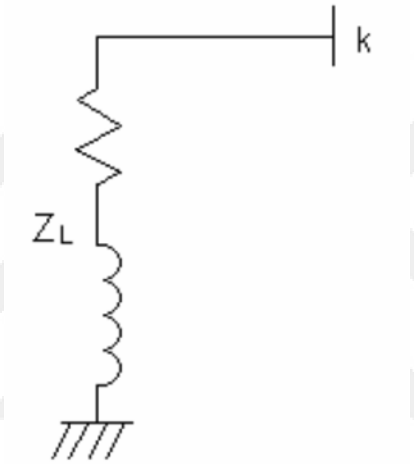
(b)

Figure 2.3: Distribution line using (a) towers, and (b) underground cables.

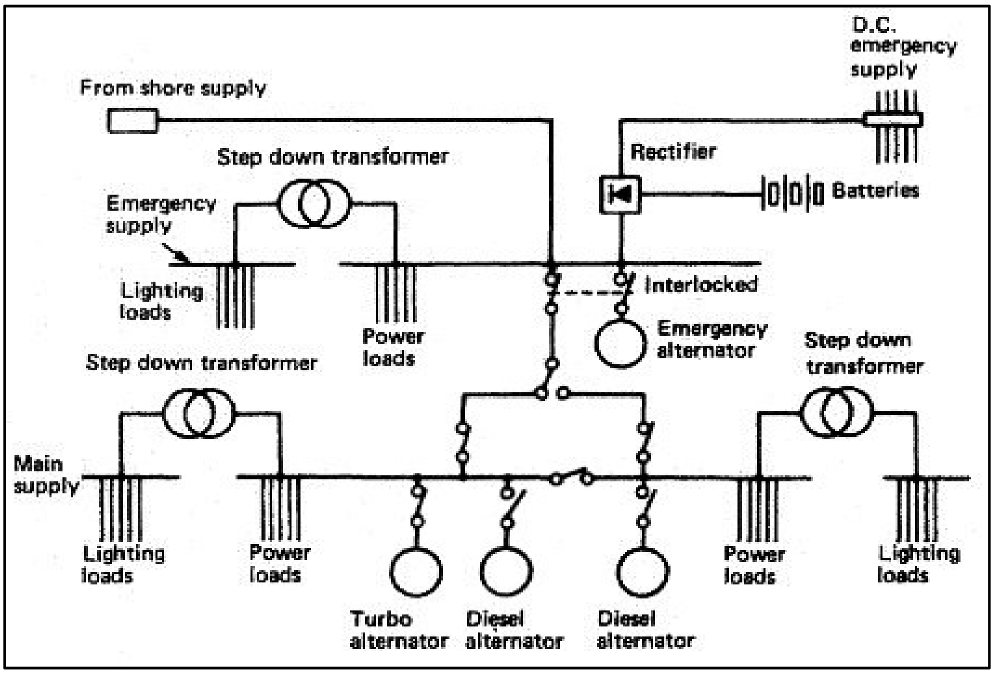
2.2.4 Load Model

Loads of power systems are divided into industrial, commercial and residential. Huge industrial loads may be supplied from the transmission system. Large industrial loads are served straight from the sub-transmission network, and small industrial loads are supplied from the primary distribution grid. Industrial loads are combined loads, and induction motors make up a high proportion of these loads. These combined loads are functions of voltage and frequency and make up a major part of a system load. Commercial and residential loads consist hugely of heating, cooling and lighting.

These loads are independent of frequency and use insignificantly small reactive power. The real power of loads is expressed in KW's or MW's. The magnitude of a load fluctuates throughout the day, and power must be available to customers on demand. The daily load curve of a utility is a combined of demands made by several classes of users. The highest value of a load during a 24-hour interval is called the peak or maximum demand. The load factor is the ratio of average load over a designated period of time to the peak load occurring in that period. Load factors may be given for a day, a month, or a year. The yearly or annual load factor is the most useful since a year represents a full cycle of time. Figure 2.4 shows a simple diagram of a load [25, 16].



(a)



(b)

Figure 2.4: Load model (a) single line diagram, and (b) distribution system.

2.3 Harmonic Sources in Distribution Systems

Many loads connected to the electricity distribution system are either a linear or near linear function of the voltage and current supplied to it. These linear loads do not usually cause disturbances or harmonics in the distribution system. However, the loads have an effect on the power factor in the electrical system depending on the type of load inductance or capacitive load, as shown in Figure 2.5. Linear loads occur as many types in the system, such as lighting, heating, directly driven motors, pumps, etc. [17, 18].

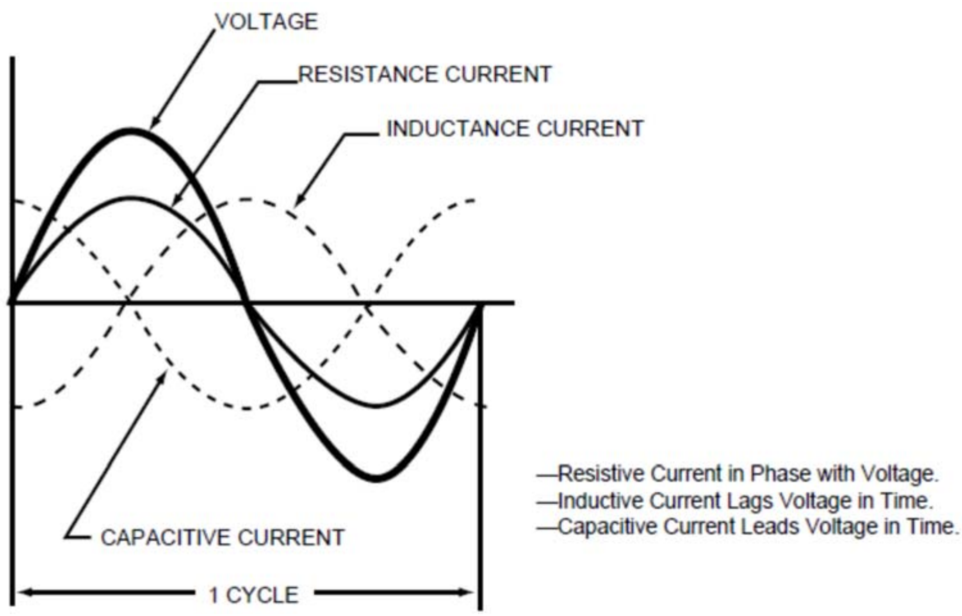


Figure 2.5: Voltage and current waveforms for linear loads.

In recent years, few industries have been using devices such as rectifiers or converters, power supplies and another devices to improve product quality. All of these make the current sinusoidal waveform distorted because the current flow was not directly proportional to the voltage. These loads are called non-linear loads. The main source of harmonics are non-linear loads which generate voltage harmonics and current harmonics because the resistance of the device is not a constant, as shown in Figure 2.6. The resistance, in fact, changes during each sine wave period. Therefore, a non-linear device is one in which the current is not proportional to the applied voltage, as shown in Figure 2.7 [19]. The non-linear components in the distribution system are as shown in the following:

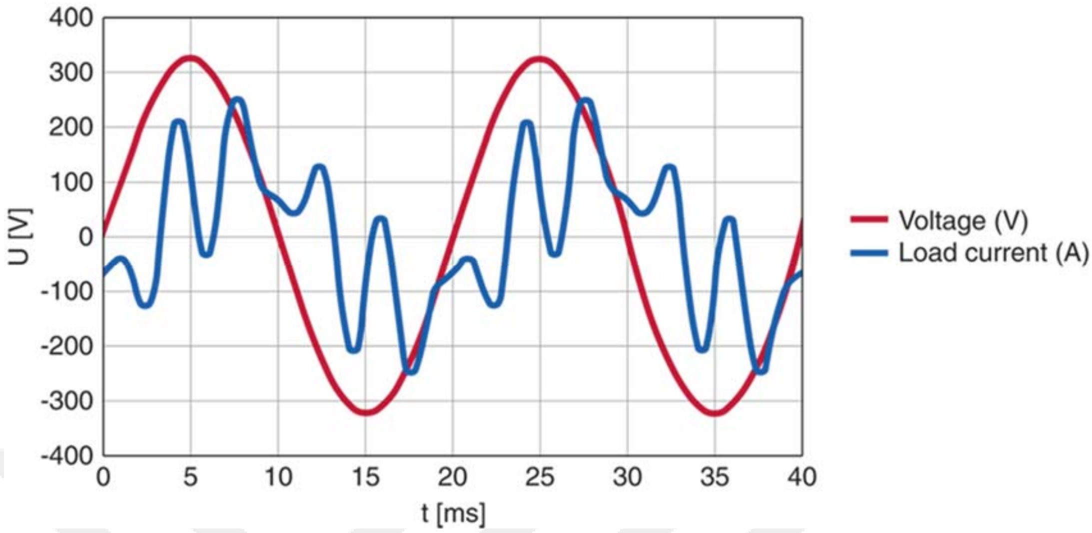


Figure 2.6: Voltage and current waveforms for nonlinear loads.

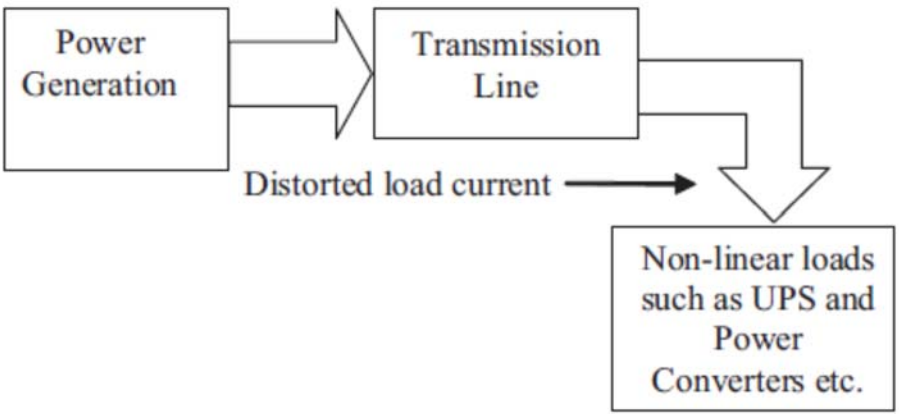


Figure 2.7: Schematic of harmonics estimation problem.

2.3.1 Transformer Harmonics

Saturation transformer conditions are created through two cases in the transformer: the first situation case is the transformer, operating above rated power in excess of the rated voltage. The second case is the transformer operating at low load, especially if utility capacitor banks are not disconnected. Figure 2.8 shows the distorter current in the transformer. The saturation current generates the magnetizing current which leads to creating the harmonics and injection into the distribution system. These harmonics are odd multiples of three, namely, the 3rd, 9th, 15th, etc. [18, 19].

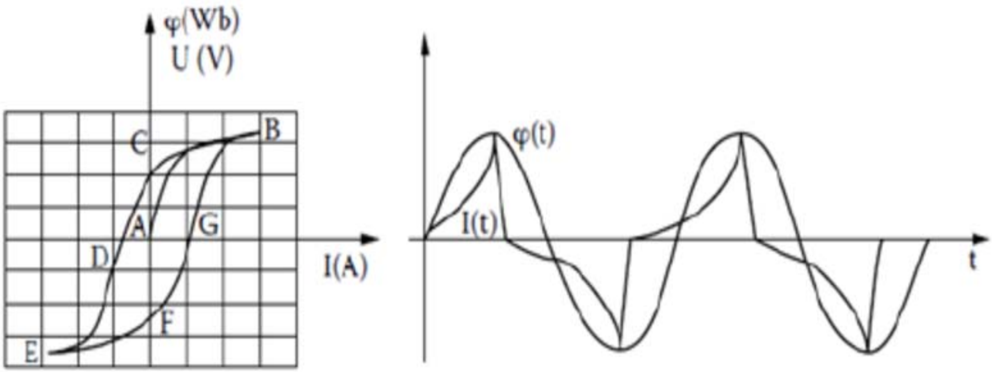


Figure 2.8: Saturation current waveform for the transformer.

2.3.2 Machine Harmonics

Current harmonics can be created through a small asymmetry on the machine, slots of the rotor or problems in the winding patterns of a three-phase winding, as shown in Figure 2.9. Therefore, the electromotive force (EMF) creates the harmonics on the stator windings. These harmonics can be added to the magnetic core saturation. However, the rotating machine harmonic produce a small value compared with other devices [19, 20].

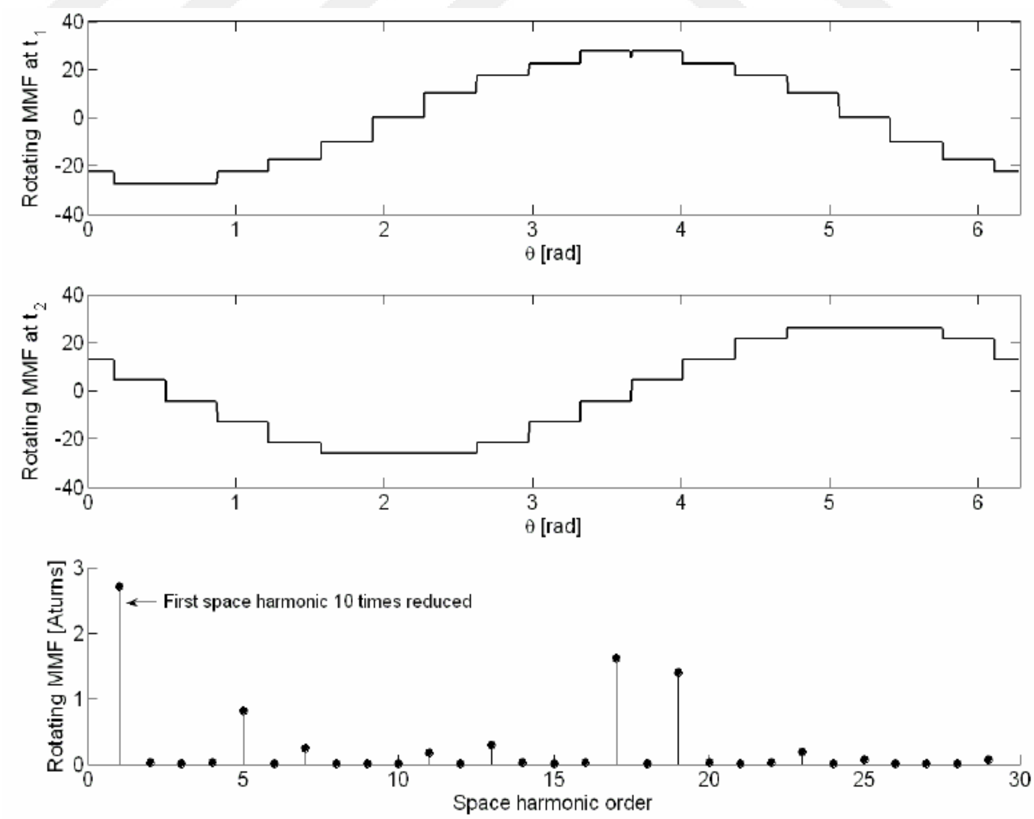


Figure 2.9: Machine harmonics.

2.3.3 Power Converters Harmonics

Power converter devices have ushered in a new era for designing power converter circuits, such as rectifier circuits (AC-DC) converters, chopper circuits (DC-DC) converters, cyclo-converter circuits (AC-AC) converters and inverter circuits (DC-AC) converters, which are utilized in many applications. A rectifier is an electrical device that transfers AC, which periodically reverses direction to DC, which flows in only one direction. Rectifiers are used in many specialist applications in transmission line systems. DC power can be converted into AC power at the desired output by a power converter circuit called an inverter. The inverter generates an AC voltage with a controlled magnitude and frequency. An inverter can be employed in various applications, including in high voltage DC transmission lines, uninterrupted power supplies (UPS), and AC power generation from a fuel cell or photovoltaic (PV) array. An inverter also plays a very important role in control systems for induction motor drives [19, 20]. These power converters an increase the harmonics in the distribution systems and are classified into four converter types.

First, large power converters are used in power systems to convert AC to DC in the DC distribution and high voltage DC. A large power converter has a large inductance lead to generate harmonics and inject them into the system [19]. Medium power converters are utilized in industrial applications, including converters with DC and AC motors. The converters can reach the value of the fifth harmonic in the distribution system that ranges from one-fifth to one-third of the fundamental rated current [2]. Low power converters in some devices such as UPS (Uninterruptible Power Supply) units (as shown in Figure 2.10), discharge lamps, television sets, computers, etc. are generated by the harmonics in the distribution system [22]. The variable frequency drive (VFD) is applied in many applications such as HVAC application, air handlers, pumps, chillers and tower fans. The VFD is created by the harmonics inside a distribution system [23]. Figure 2.12 shows a simple VFD system.

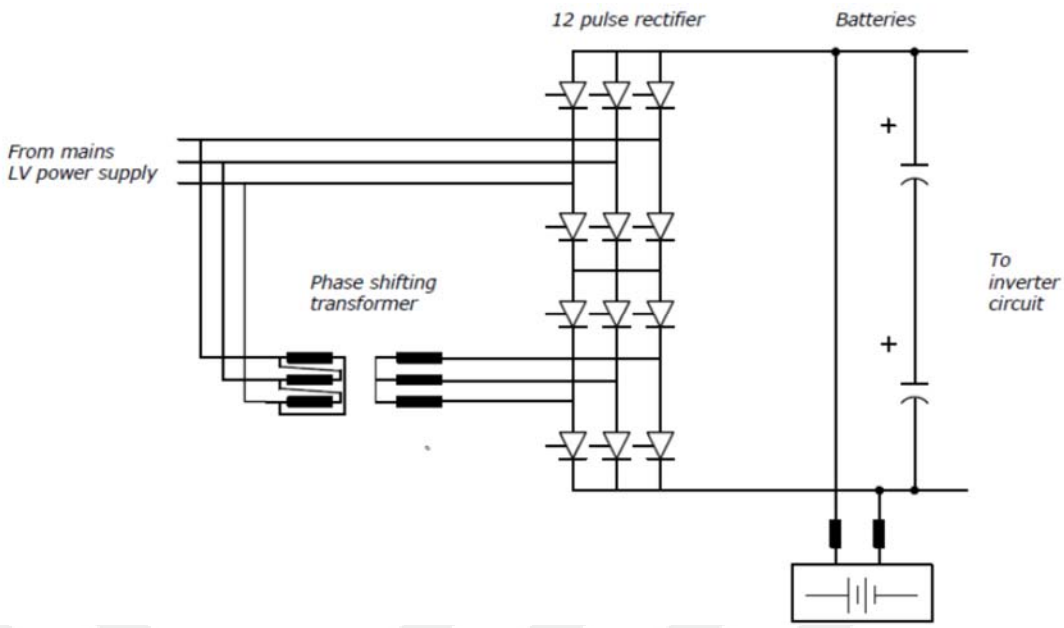


Figure 2.10: UPS battery charger configuration diagram.

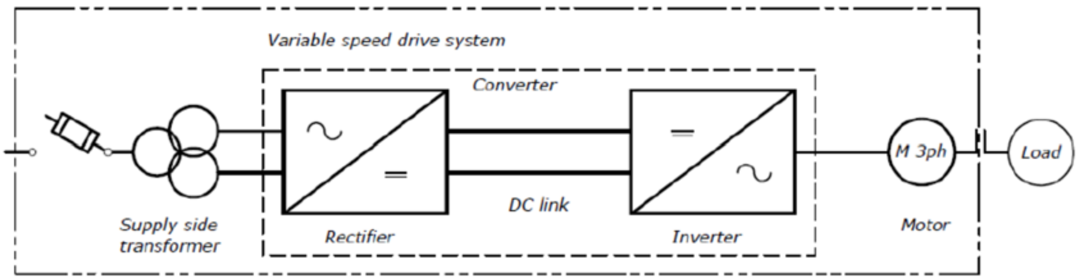


Figure 2.11: A simple representation of a VFD system.

2.3.4 Fluorescent Lamps

Fluorescent lamps are one of the main nonlinear loads, which have an effect on the distribution system, as shown in Figure 2.12. Fluorescent lamps consist of high inductance inductors inside the start ballasts which function to limit the current to the tube. Therefore, fluorescent lamps have a capacitor to increase efficiency and increase the power factor. The inductance and the capacitor generate the distortion factor in the voltage and current waveforms [19].

Figure 2.12: Fluorescent lamps.

2.4 Power System Filters Methods

Filters may be of two types such that there is a combination of active elements (transistors, op-amps) known as active filters and a combination of passive elements (R, L, and C) known s passive filters. Filters are used to minimize or remove any unwanted frequencies [24]. In this thesis, the passive filter is used and a short description about the active filter is briefly presented.

2.4.1 Passive Filter

Passive filters consist of R, L, and C elements which are designed, arranged and tuned to remove harmonics and stop harmonic currents. They supply reactive power compensation to a system and improve power quality. The passive filter has a disadvantage: its increases harmonics in the system because of the incompatibility of the passive filter elements with the system. The passive filter has many types, such as single tuned filters, double tuned filters, reactance filter, and so on. [12, 24].

a. Single Tuned Filter:

The single tuned filter (STF) is a shunt passive filter used to reduce harmonics. It is the most common type of filter in distribution systems because of its simple structure and low cost, as shown in Figure 2.13 [10].

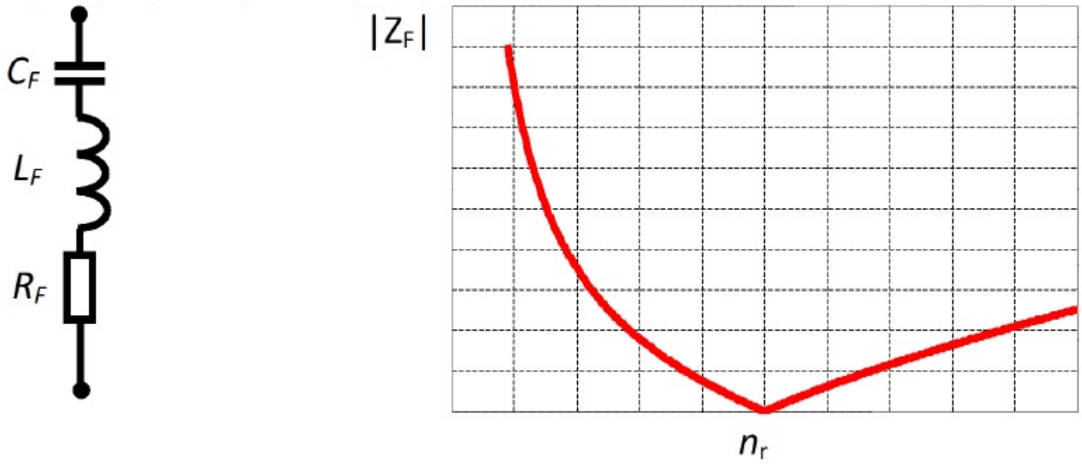


Figure 2.13: Single tuned filter.

b. Double Tuned Filter:

The double tuned filter (DFT) consists of a series connection for inductance and a capacitor connected the series with a second inductor and capacitor as shown in Figure 2.14. The DTF operates by minimizing the two-level harmonics simultaneously with the DTF impedance structure. The DTF has a few advantages, such as only one reactor being subjected to full line voltage, its losses being much lower and lower impedance magnitude at the frequency of the parallel resonance [12].

In our case the series resonance (f1) and parallel resonance (f2) were, f1= 291.8 Hz and f2= 300 Hz, respectively.

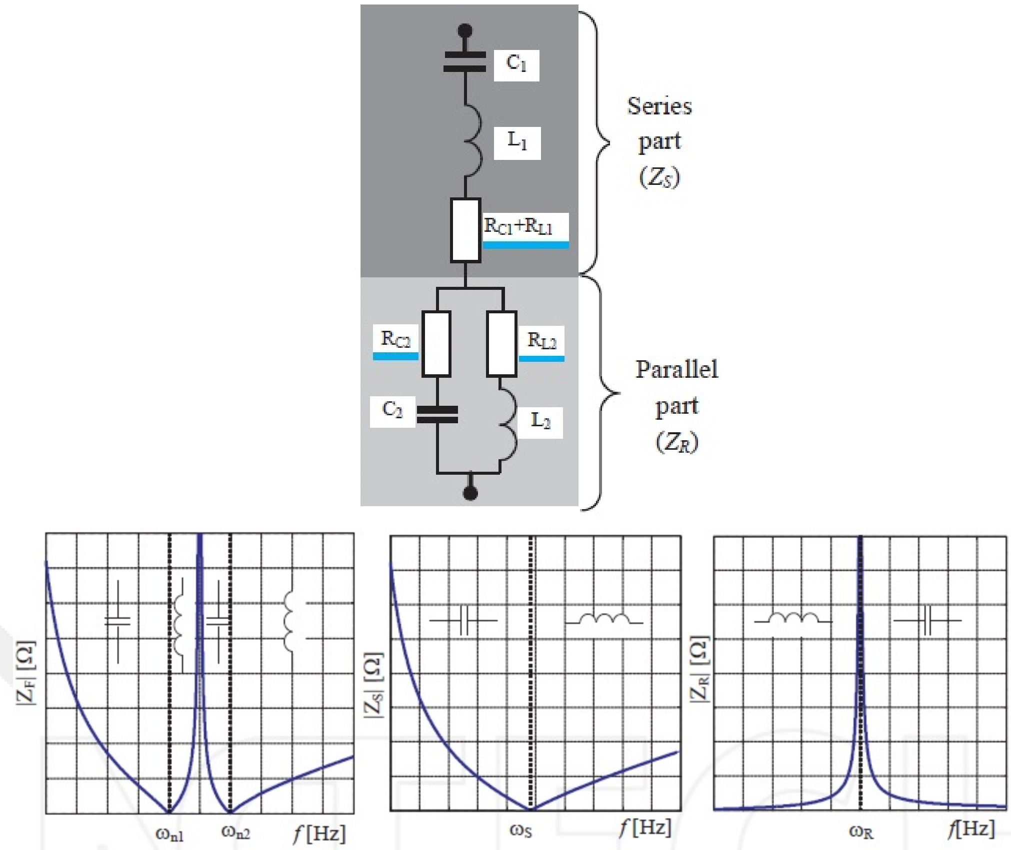


Figure 2.14: Double tuned filter.

c. Reactance Filter:

The reactance filter is used for harmonic reduction, as shown in Figure 2.15. This filter achieves minimum voltage and current distortion with its components. The susceptance of the reactance filter should be equal to the equivalent load but with the opposite sign. [12].

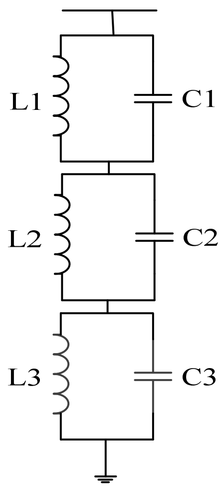


Figure 2.15: Reactance filter.

2.4.2 Active Filter

Active filters are used to eliminate harmonics in the voltage and current waveform. These filters consist of electronic elements such as transistors and operation amplifiers, so they are expensive and difficult structures. However, they have the advantage of not resonating with the distribution system, and they are independent of the impedance of the system. The active filter can remove many harmonics simultaneously [6, 24].

2.5 Harmonic Indices

The two indices most commonly used to assess the performance of the electrical distribution system are by measuring the harmonic content of a waveform, which can be either the Total Harmonic Distortion for the current (THDi) or the Total Harmonic Distortion for the voltage (THDv) [25]. THD is the ratio defined as the sum of all harmonic components (voltage and current) divided by the fundamental component. The THDi and THDv can be calculated thus [3, 25]:

$$THD_i = \frac{1}{I_1}\sqrt{\sum_{n=2}^{\infty}(I_n)^2} \qquad (2.1)$$

$$THD_v = \frac{1}{V_1}\sqrt{\sum_{n=2}^{\infty}(V_n)^2} \qquad (2.2)$$

where n is the order of harmonics, I_n, I_1 are respectively the harmonic and fundamental currents, and V_n, V_1 are respectively the harmonic and fundamental voltages.

2.6 Standard limits of Harmonic Distortion

The standard limits for the distortion of voltages and currents are allowed by the IEEE and IEC according to the following tables [24, 27]:

Table 2.1: Current distortion limit of general distortion system.

Current Distortion Limits for General Distribution Systems

(120 V Through 69000V)

Maximum Harmonic Current Distortion in Percent of IL						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<11	$11\leq h<17$	17≤h<23	23≤h<35	35≤h	TDD
<20*	4	2	1.5	0.6	0.3	5
20<50	7	3.5	2.5	1	0.5	8
50<100	10	4.5	4	1.5	0.7	12
100<1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20
Even harmonics are limited to 25%of the odd harmonic limits above.						
Current distortions that result in a dc offset. e.g. half-wave converters, are not allowed.						
***All power generations equipment is limited to these values of current distortion, regardless of actual I_{SC}/I_L.**						
Where **I_{SC} = maximum short-circuit current at PCC.** **I_L =maximum demand load current (fundamental frequency component) at PCC.** **TDD =Total demand distortion (RSS). Harmonic current distortion in % of maximum demand load current (15 or 30 min demand).** **PCC =Point of common coupling.**						

IEEE 519 harmonic current limit

Table 2.2: Voltage distortion limit of general distortion system.

Voltage Distortion Limits

Bus voltage at PCC	Individual voltage distortion (%)	Total voltage distortion THD (%)
Below 69 KV	3	5
69KV to 161KV	1.5	2.5
161KV and above	1	1.5
NOTE: High-voltage systems can have up to 2% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.		

IEEE 519 harmonic voltage limit

CHAPTER THREE

DEVELOPMENT OF DISTRIBUTION SYSTEM FILTERS USING PARTICLE SWARM OPTIMIZATION

3.1 Introduction

This chapter presents the design of a simulation model of the distribution system model, which is the Iraqi-Hai Tunis distribution. Moreover, the single tuned filter, double tuned filter and reactance filter were designed in the distribution system. This chapter also will explain the particle swarm optimization (PSO) algorithm. The proposed PSO-based power filters in the distribution system are presented in this chapter.

3.2 Simulation Model of a Distribution System

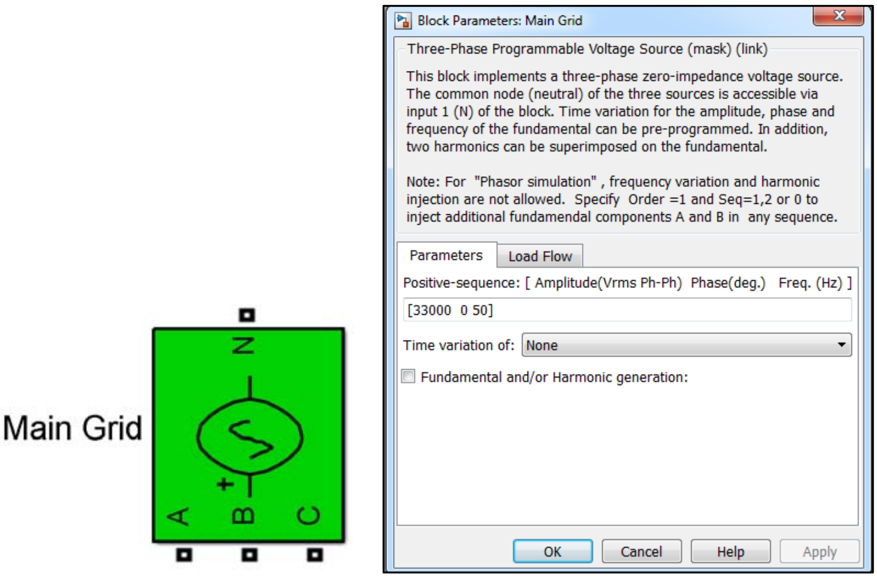
In this thesis, the real Iraqi-Hai Tunis distribution system used to analyze and minimize the harmonics and the system. Figure 3.1 shows a snapshot of the actual Iraqi-Hai Tunis distribution system map.

The distribution system consists of many components, namely generators, distribution lines, transformers, loads, and capacitors. The chosen distribution system was designed using the MATLAB/SIMULINK package and each distribution components are as follows:

Figure 3.1: Snapshot of the Iraqi-Hai Tunis distribution system.

3.2.1 Simulation of the Main Grid

A three-phase voltage source block is represented in the main grid in the simulation distribution model, as shown in Figure 3.3(a). This block can configure the voltage amplitude (RMS), phase (degree) and frequency (Hz). In this thesis, the amplitude of 33 kV, phase 0°, and a frequency of 50 Hz are used, as shown in Figure 3.3(b).



(a) (b)

Figure 3.3: Three-phase voltage source (a) block, and (b) configuration.

3.2.2 Simulation of Transformers

There are two types of step-down transformer in the Iraqi-Hai Tunis distribution system, namely one 33/11 kV transformer and sixteen 11/0.4 kV transformers. The three-phase transformer block is represented as the step-down transformer in the distribution simulation model, as shown in Figure 3.4(a). This block can select the primary and secondary winding connections in the distribution systems, which is a star-delta connection. Moreover, we can configure the transformer parameters of the rated power, frequency, resistance, reactance, and magnetic reactance for the primary and secondary windings, as shown in Figure 3.4(b). This thesis utilizes the real values of the transformer parameters by using the transformer data sheet, as shown in Appendix A.

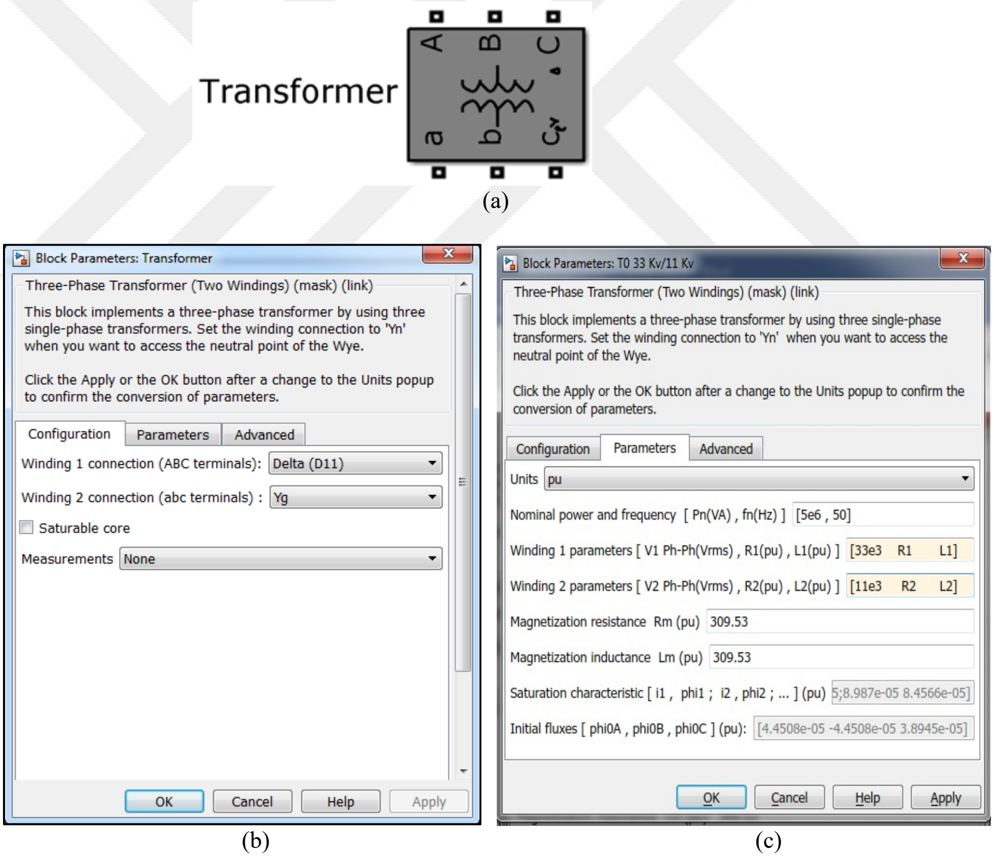


Figure 3.4: Three-phase transformer (a) block, (b) configuration, and (c) parameters setting.

3.2.3 Simulation of Distribution Lines

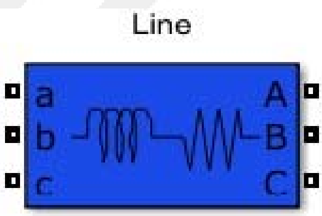
A distribution line consists of a resistive cable and inductance cables (self and mutual reactance cables). Therefore, a distribution line can be represented as being a resistive and inductive series connection. The resistivity and inductance of distribution lines are calculated as shown in the following equations [25]:

$$R = \rho \times \frac{l}{A} \tag{3.1}$$

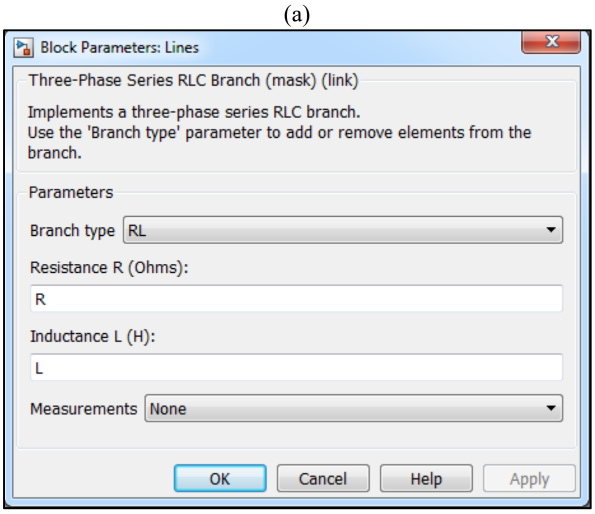
$$L = 2 \times 10^{-4} \ln\left(\frac{D_{eq}}{\bar{r}}\right) \times l \tag{3.2}$$

where $R(\Omega)$ is the resistive line, $A(m^2)$ is the cross section area, $l(m)$ is the line length, ρ is the resistivity of the conductor, $L(H)$ is the inductance of the line, $D_{eq} = \sqrt[3]{D_{ab}D_{bc}D_{ca}}$, D is the distance between the two cables, and $\bar{r} = \sqrt{0.7788\, r}$, r is the radius of the cable.

A three-phase series RLC branch block represents the distribution lines in the distribution simulation model, as shown in Figure 3.5(a). This block can be selected for the resistive and inductance lines in the Iraqi-Hai Tunis distribution system. The Iraqi-Hai Tunis distribution system has nineteen lines. Moreover, we can configure the line parameters to be resistive and inductive, as shown in Figure 3.4(b). In this thesis, we use the real values of the line parameters by using the line data sheet, as shown in Appendix B.



(a)



(b)

Figure 3.5: Three-phase distribution lines (a) block, and (b) configuration.

3.2.4 Simulation of Load and Capacitor

The Iraqi-Hai Tunis distribution system has RL loads and a capacitor to improve the power factor. The number of loads and capacitor is sixteen loads. The three-phase series RLC load block represents the distribution load or capacitor in the simulation model, as shown in Figure 3.6(a). This block can configured the voltage (RMS), frequency (in Hz), active power (in W), inductance reactive power (Var) and capacitor reactive power (Var) in the two distribution systems, as shown in Figure 3.6(b).

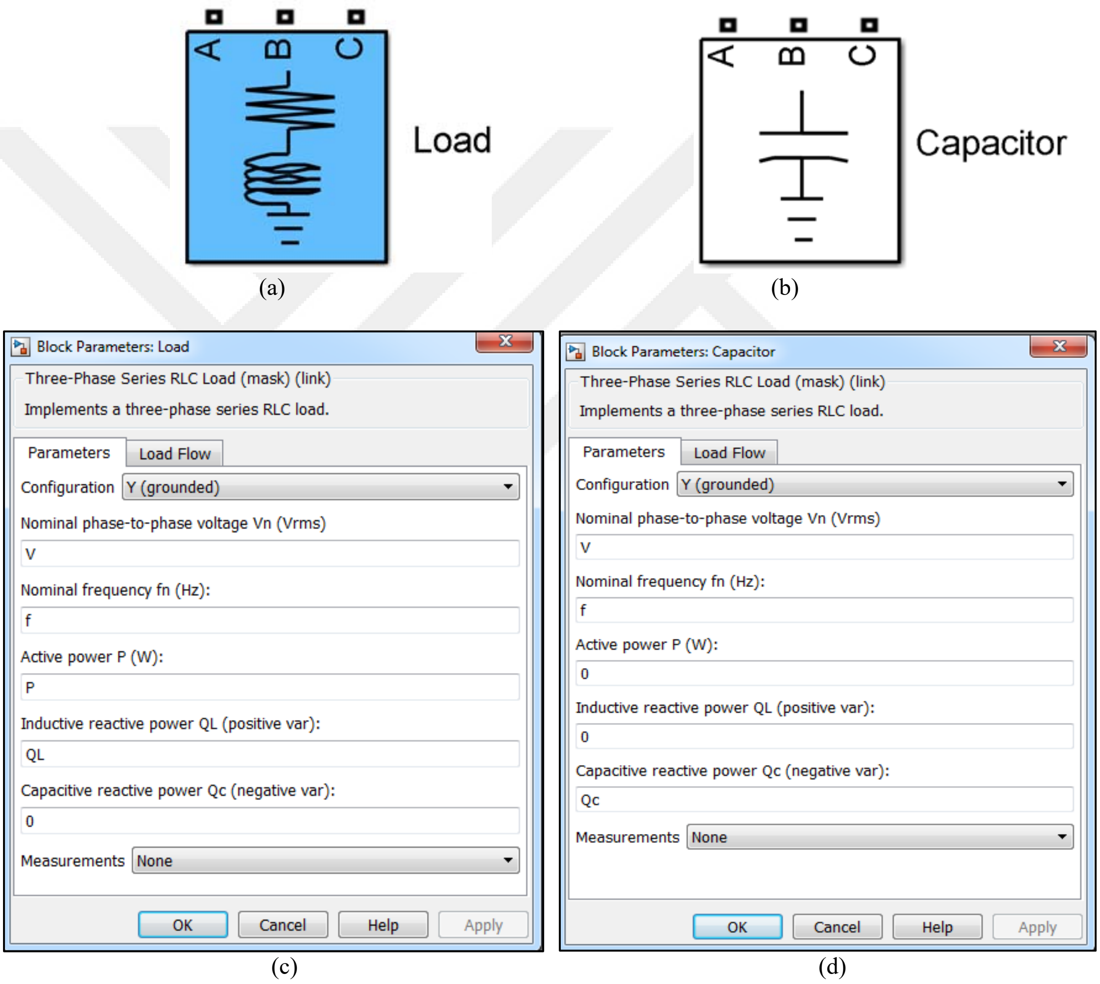


Figure 3.6: Three-phase distribution (a) load block, (b) capacitor block, (c) configuration load, and (d) configuration capacitor.

3.2.5 Simulation Model of the Iraqi-Hai Tunis Distribution System

The Simulation model of the Iraqi-Hai Tunis distribution system is designed in MATLAB/SIMULINK. Figure 3.7 shows the overall structure of the Iraqi-Hai Tunis distribution system model.

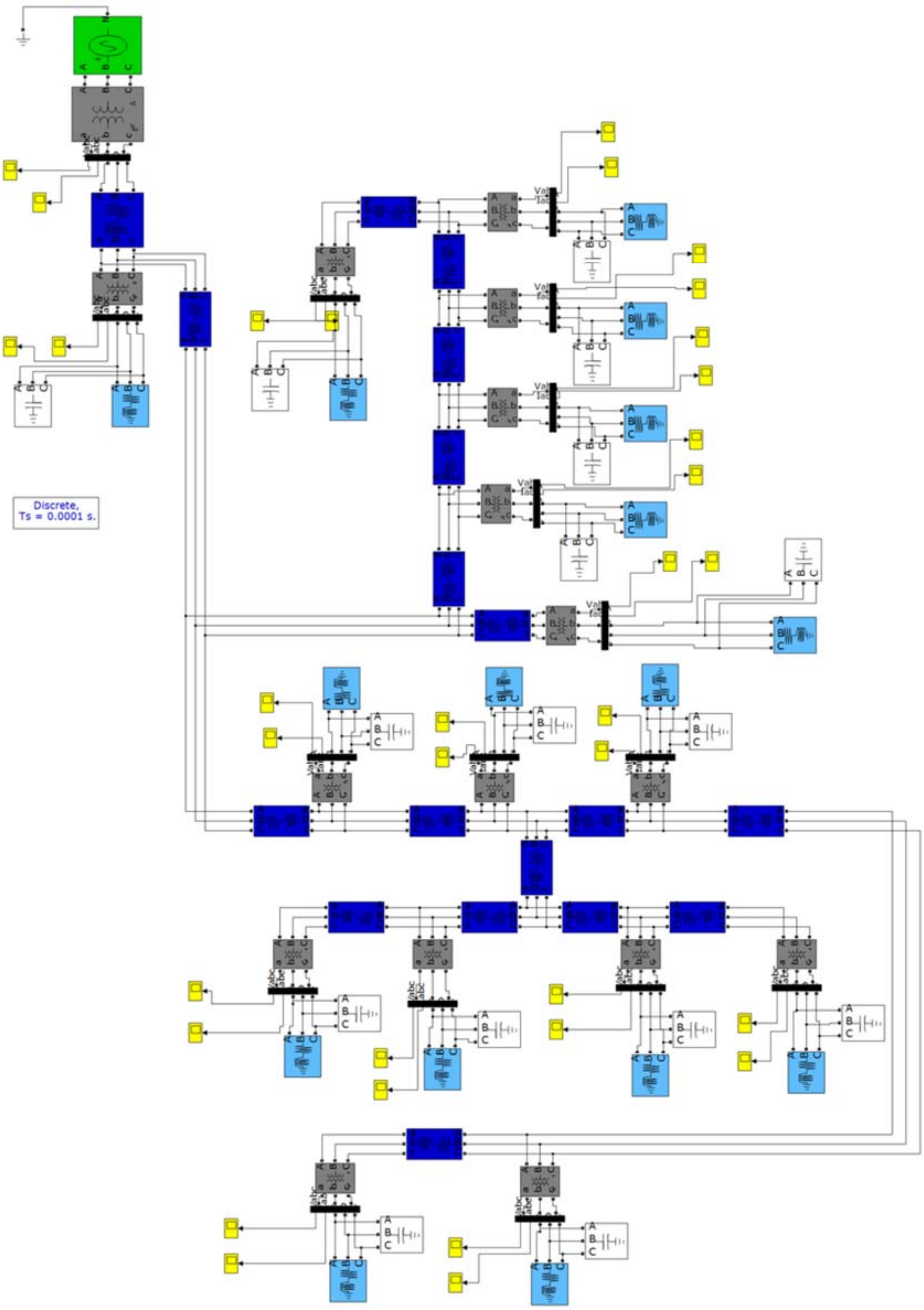


Figure 3.7: Simulation Model of the Iraqi-Hai Tunis distribution system.

3.3 Harmonic Generator Model

The proposed harmonics generator in the distribution system in this thesis adds two factories to the 17-bus and 18-bus of the Iraqi-Hai Tunis distribution system. Moreover, These factories are represented in the distribution system as an adjustable speed drive (ASD) because an ASD can inject the many harmonics into the distribution system to become a distribution system that has many harmonics to analyze. The ASD has power electronic devices to design converters, for example rectifiers, inverters, and DC-DC converters. Switching techniques are used to adjust the three-phase induction motor drive. Accordingly, adjustable speed drive (ASD) methods are designed and developed in research for control purposes. An induction motor is explored in terms of improving speed control, implementation of a motor control strategy, and decrease of energy losses [3, 12]. The ADS system consists of the three-phase inverter, three-phase motor, pulse width modulation (PWM) switching technique and the control system, as shown in Figure 3.9. Figure 3.10 shows the simulation model of the ASD.

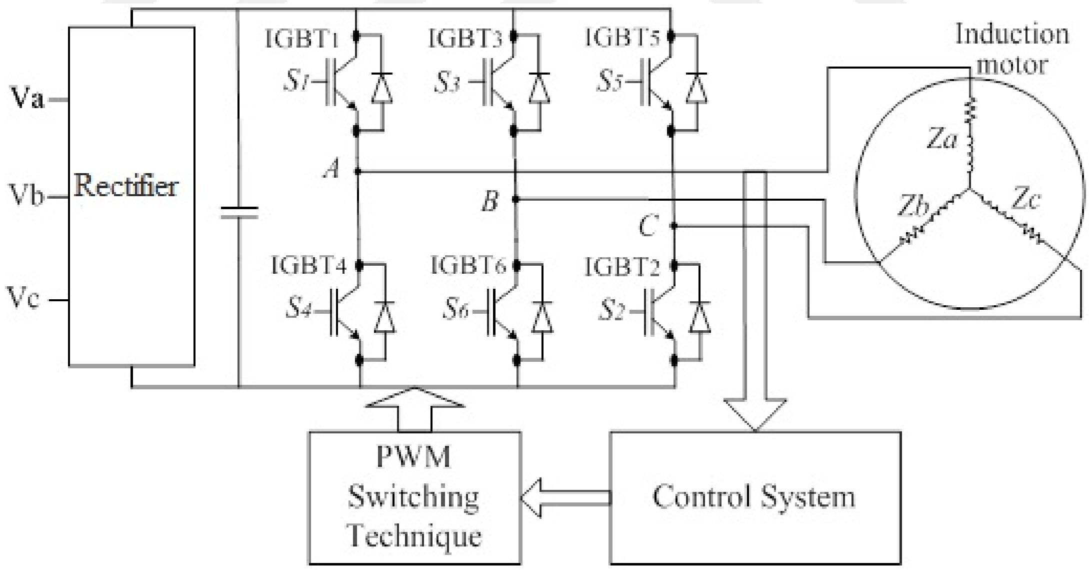


Figure 3.9: ASD structure.

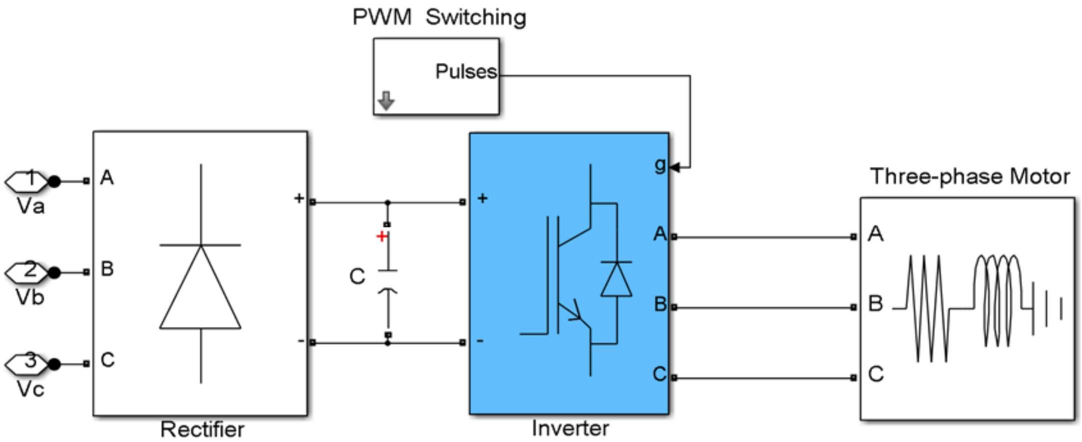


Figure 3.10: Simulation model of ASD.

3.4 Design of Power Filters

In this thesis, we used three types of filter to minimize the harmonics of the distribution system. The recommended filters were used in the distribution system, which were a single tuned filter, a double tuned filter and a reactance filter. All filters were implemented and utilized in the Hai Tunis distribution system modeling the filters in the simulation system. Figures 3.11(b) and 3.11(c) show the simulation model of a single tuned filter, a double tuned filter and a reactance filter, respectively.

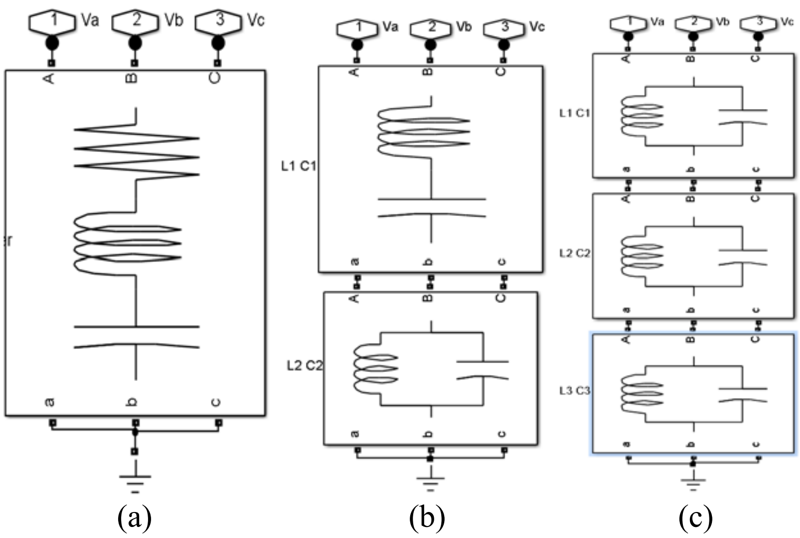


Figure 3.11: Filter models for (a) single tuned filter, (b) double tuned filter, and (c) reactance filter.

3.5 Simulation Model With Factories and Filters

In this work, we suggest adding two factories to the 17-bus and 18-bus of the Hai Tunis distribution system, as shown in Figure 3.12. As a result, the distribution system produces harmonics in the system. Figure 3.12 shows the addition of two filters near the factories to minimize the harmonics.

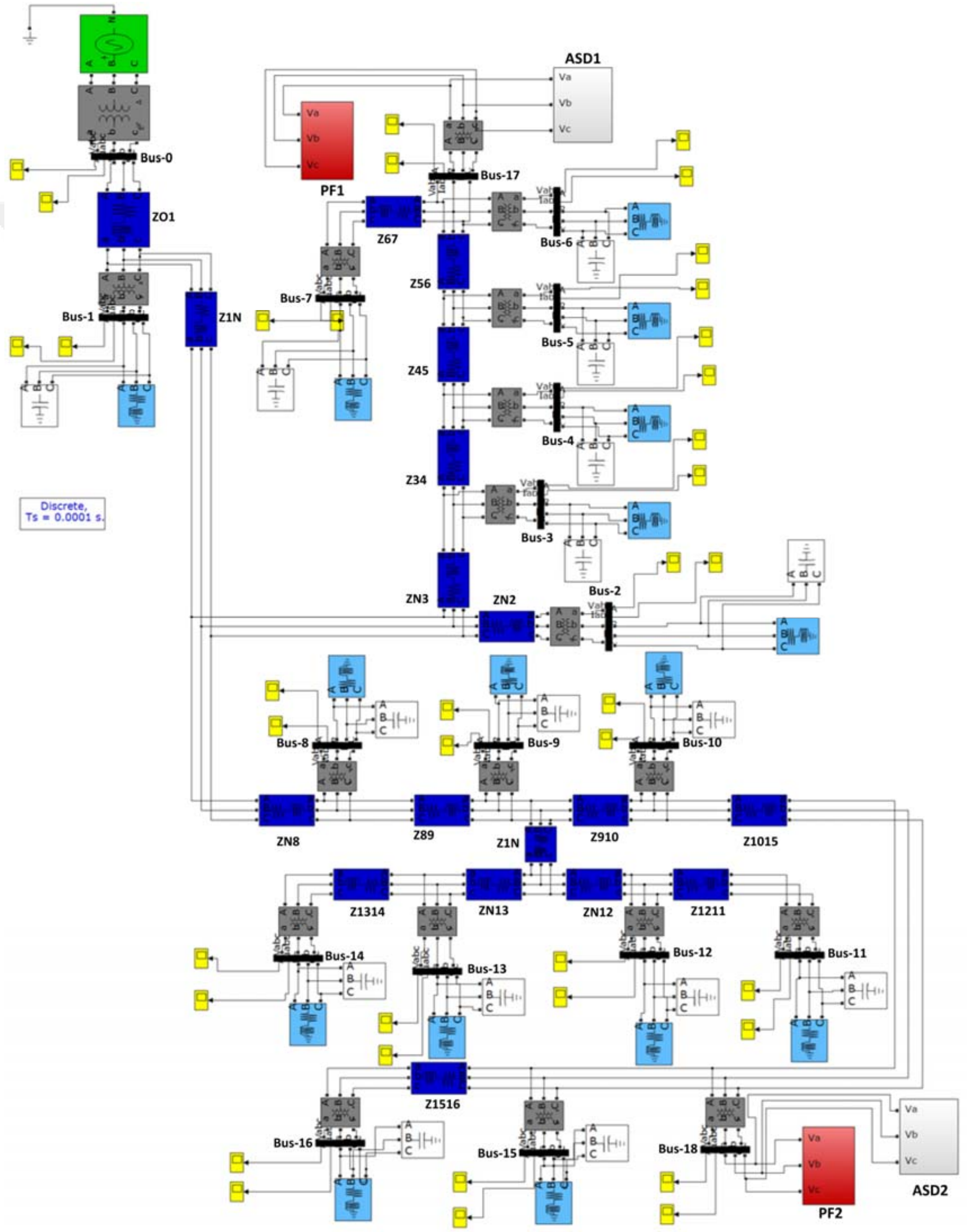


Figure 3.12: Simulation model of Hai Tunis distribution system with two factories and filters.

3.6 Particle Swarm Optimization Algorithm

PSO is a sophisticated computation method developed by Eberhart and Kennedy (1995), which was inspired by the social attitude of bird flocking, as shown in Figure 3.14. It is applied by several researchers because of its proven robustness, ease of application, and global exploration capability in several applications [26]. The particles in the PSO algorithm search the space in two locations. The first one is the optimum point where the swarm finds the current iteration (local best). The second location is the optimum point found through all previous iterations (global best). The base of the PSO algorithm depends on two factors, namely velocity and position of particles. These factors can be updated by employing the following equations [27]:

$$V_i^d(t+1) = wV_i^d(t) + c_1r_1\left(P_i^d(t) - X_i^d(t)\right) + c_2r_2\left(P_t^d(t) - X_i^d(t)\right) \quad (3.3)$$

$$X_i^d(t+1) = X_i^d(t) + V_i^d(t+1) \quad (3.4)$$

where c_1 is the social rate, and c_2 is the cognitive rate, r_1 and r_2 denote the randomness in the interval (0, 1), V is the velocity factor of agent i at iteration d, t is the present iteration, w is the inertia factor, and X is the position factor.

Represent the randomness in the period (0, 1), V is the velocity factor of agent i at iteration d, t is the sitting iteration, w is the inertia factor, and X is the position factor.

The PSO algorithm is performed in many applications, such as in [34] to adjust the threshold parameters of the rule-based power management strategy for hybrid electric vehicles and to resolve the optimal power flow issue of power systems [35]. The PSO algorithm is used to improve the maximum power point tracking (MPPT) method to control the rotor side converter of a wind turbine fed induction generator [30]. A PSO is applied to determine the ideal sizing of a hybrid PV, battery and wind system [31].

Figure 3.14: Bird flock.

3.7 Proposed PSO-Based Distribution System Filters

Recently, the power filter in the distribution system has been used to improve systems by minimizing the harmonics in the voltage and currents thereby leading to a reduction of loss in the distribution system. The passive filter is one of these filters applied in the distribution system. It has advantages, namely, a good and fast response because it consists of a resistor, inductor, and capacitor and it does not require an external source [6, 7]. However, these filters require sizing and setting of suitable values of the filter components in the electric distribution system [11, 14]. Therefore, in this work, the PSO algorithm is used to find suitable values to distribute filters parameters so as to enhance the filter work in the Hai Tunis distribution system by minimizing the total harmonic distortion (THD) for the voltages and currents.

The PSO technique includes two crucial elements, namely the input of information and an objective function. Each component works for amendment and classification to achieve an optimal distribution of filter parameters. The optimization method is searched to get the best solution by reducing the objective function, although the input data and the selection of the constraints in each generation of the iterative procedure are manipulated.

3.7.1 Input Information

The input data for the PSO algorithm of the distribution filter parameters in this work use three types of distribution filter. First, the single tuned filter (STF) has three parameters for each filter, namely resistive (R), inductive (L) and capacitive (C), as shown in Figure 3.10(a). Second, the double tuned filter has four parameters for each filter, namely two inductances (L1 and L2) and two capacitances (C1 and C2), as shown in Figure 3.10(b). Third, the reactive filter has six parameters for each filter, namely three inductances (L1, L2, and L3) and three capacitances (C1, C2 and C3), as shown in Figure 3.10(c).

The input matrix consists of many columns and rows. The number of columns generated by the numerical values to the filter parameters and the number of rows produced by the size of populations are shown in the following matrix:

$$D_{ij} = \begin{bmatrix} X_{11} & \cdots & X_{1j} \\ \vdots & \ddots & \vdots \\ X_{i1} & \cdots & X_{ij} \end{bmatrix} \tag{3.5}$$

where D is input data for the optimization technique; $i = 1,2, \ldots \ldots, P$, P is the number of populations; $j = 1,2, \ldots \ldots, N$, and N is the problem dimension.

3.7.2 Objective Function

An objective function is the required target of the optimization technique to obtain lower power loss. Thus, the objective function searches for the best value of the filter parameters to minimize the voltage and current harmonics. Summation, the total harmonic distortion for voltages (〖THD _v) and the total harmonic distortion for currents 〖THD _ i), are used as objective functions to obtain suitable filter parameters for better results. The objective function is calculated as follows:

$$Objective\ function = \sum_{n=1}^{N} (THDv_n + THDi_n) \tag{3.6}$$

where N is the number of buses, $THDv_n$ is total harmonics distortion of the voltages for each bus, $THDi_n$ is total harmonics distortion of the currents for each bus.

Figure 3.15 shows the operational flow of the PSO-based distribution system power filter.

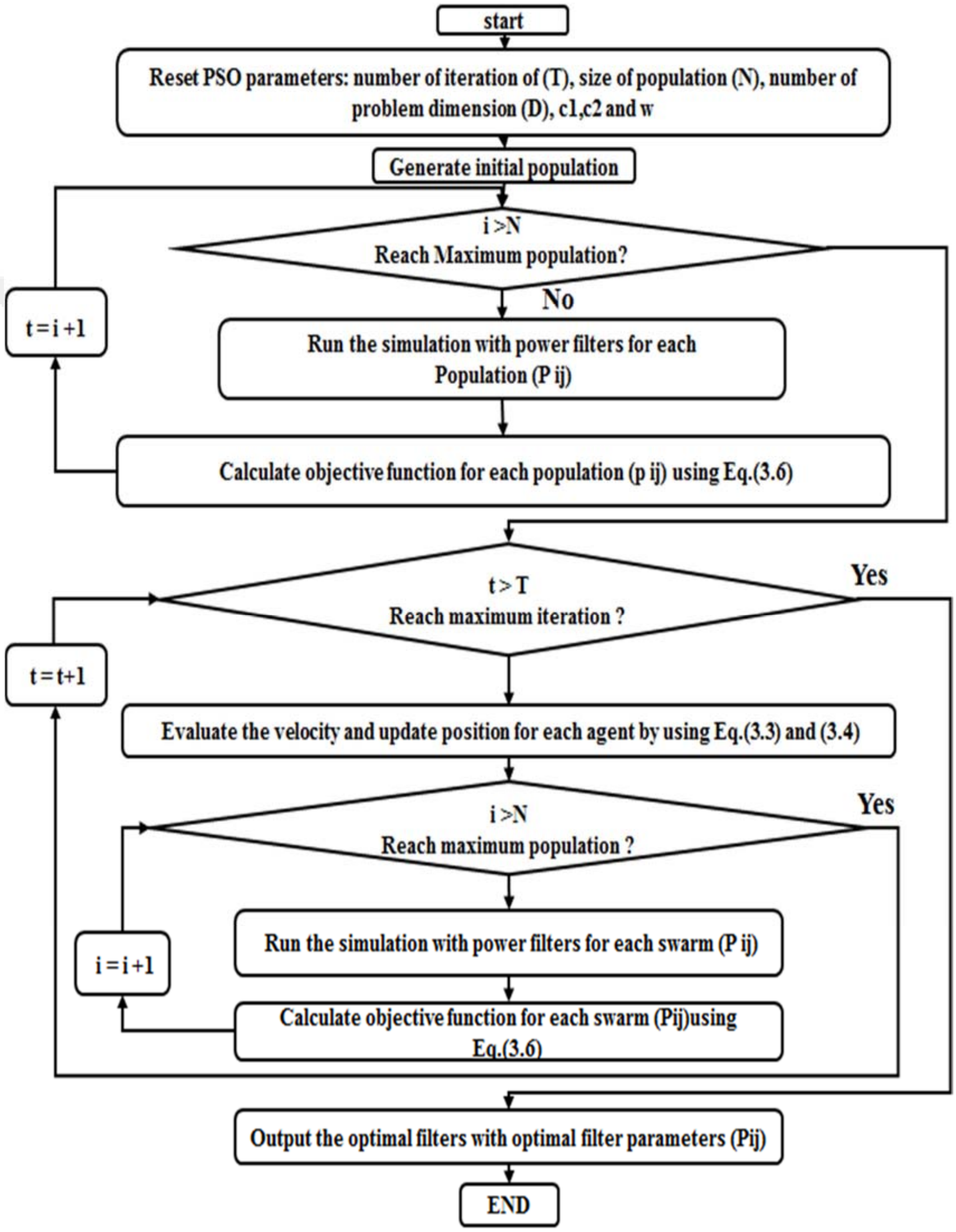


Figure 3.15: Proposed PSO-based optimum power filter design procedure.

Table 3.1: input data for PSO.

Parameters	Value
Iteration (T)	1.5
Swarm size (N)	1.5
Social rate $(c1)$	0.5
Cognitive rate (c_2)	200
Inertia factor (w)	20

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The simulation results are presented and discussed in this chapter to validate and justify the objective of this research. In this work, the distribution system components data for the Iraqi-Hai Tunis distribution system is presented. The proposed optimization algorithm system results are presented for STF, DTF and RF in the Iraqi-Hai Tunis distribution system. This chapter presents and discusses the simulation results and analysis of the PSO-based power filters for the distribution system. Results of the proposed PSO-based power filters on the Iraqi-Hai Tunis distribution system is presented.

4.2 Data of the Iraqi-Hai Tunisia Distribution System

The Iraqi-Hai Tunis distribution system is considered with the data given in the following tables. The cable details in the Hai Tunis distribution system are shown in Table 4.1 and Appendix B. Equations 3.1 and 3.2 are used with the line length to calculate the resistance and inductance of each line to design the distribution lines, as shown in Table 4.1, Figure 4.1 shows the arrangement of conductors in the distribution system.

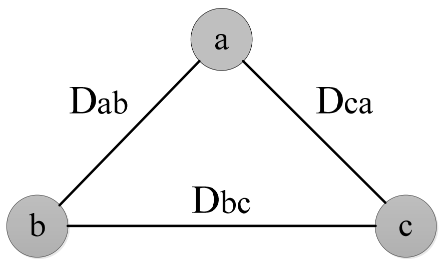


Figure 4.1: Arrangement of line conductor.

Table 4.1: Distribution line details.

Line parameters	Values
r	0.006 m
ρ	$2.65 \times 10^{-8}\ \Omega.m$
A	120 mm^2
D_{ab}	1.08 m
D_{bc}	1.20 m
D_{ca}	1.08 m

This system has two types of transformer in the system, namely one of 33/11 kV and also sixteen of 11/0.4 kV. The 11/0.4 kV transformer consists of three types rated at 630 KVA, 400 KVA, and 250 KVA. Table 4.2 shows the transformers details, namely power and voltage rated, resistance and reactance of the primary and secondary windings as well as the mutual reactance between windings. Table 4.3 shows data for three types of 11/0.4 kV transformer, namely 630 kVA, 400 kVA, and 250 kVA. More details of the transformers in the datasheet are shown in Appendix B

Table 4.2: 33/11 kV transformer details.

Transformer parameters	Values
Power rated	5 MVA
Frequency rated	50 Hz
Primary voltage	33 kV
Secondary voltage	11 kV
Primary resistive	1.6 Ω
Primary reactance	0.039 H
Secondary resistive	0.178 Ω
Secondary reactance	0.0033 H
Magnetization resistance	0.202 MΩ
Magnetization reactance	643.77 H

Table 4.3: 11/0.4 kV transformer details.

Transformer parameters	Values		
	630 kVA	**400 kVA**	**250 kVA**
Frequency rated	50 Hz	50 Hz	50 Hz
Primary voltage	11 kV	11 kV	11 kV
Secondary voltage	0.416 kV	0.416 kV	0.416 kV
Primary resistive	1.465 Ω	5.4 Ω	3.4 Ω
Primary reactance	0.028 H	0.039 H	0.064 H
Secondary resistive	0.0019 Ω	0.0031 Ω	0.0044 Ω
Secondary reactance	0.03702 mH	0.0515 mH	0.0842 mH
Magnetization resistance	0.1738 MΩ	0.2809 MΩ	0.4494 MΩ
Magnetization reactance	567.7 H	894.13 H	1430.6 H

Finally, the capacitor added to each bus improves the power factor. Its value is 2000 KVAR, as shown in Figure 3.11.

4.3 Proposed PSO-Based Filters Algorithm Results

The PSO algorithm determines the optimal power filters in the distribution system to minimize the total harmonic distortion (THD) for voltage and currents in the buses, whereas the proposed PSO-based optimal power filters determine the minimum THD in the distribution system. The proposed algorithm is applied to the three filters, namely the STF, DTF and RF. For a fair comparison, we executed the PSO algorithm-based filters in the distribution system and selected 20 swarms and 100 iterations. The proposed algorithm system was applied to the Iraqi-Hai Tunis distribution system as follows:

4.3.1 Results of the PSO Algorithm in the Iraqi-Hai Tunis distribution system

The PSO algorithm improved two STFs near factories in the Iraqi-Hai Tunis distribution system. Obtained from the minimum value for the objective function is 0.112 in the 7 iterations, as shown in Figure 4.2. A PSO-based STF is obtained on two STF values per phase, as shown in Table 4.5.

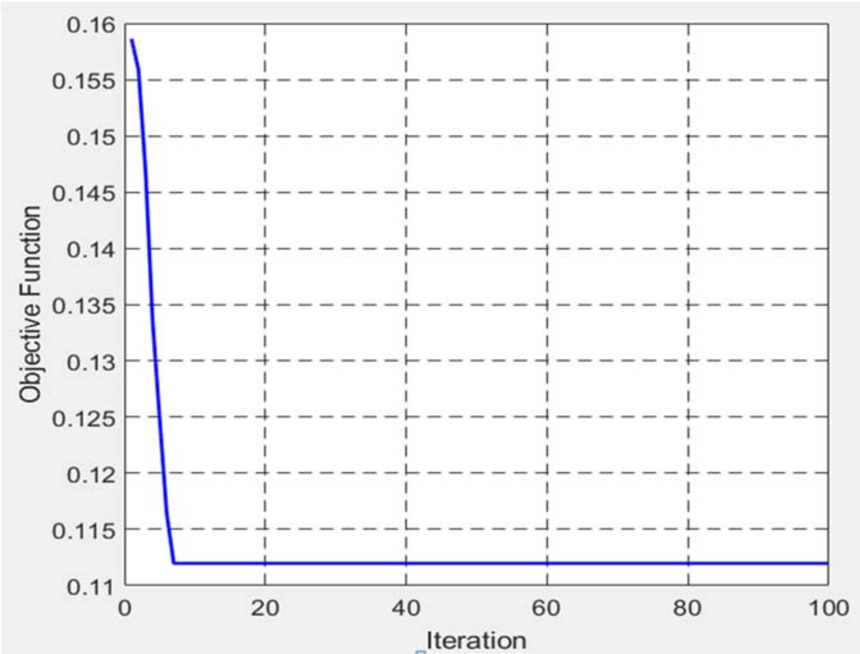


Figure 4.2: Objective function curve of a PSO-based STF in the Hai Tunis system.

Table 4.4: Optimal values of the two STF parameters for the Hai Tunis system.

First STF Parameters	Values
R	0.0154 Ω
L	0.027025 mH
C	10.00 mF
Second STF Parameters	Values
R	0.0153 Ω
L	0.026867mH
C	9.900 mF

Figure 4.3 and Figure 4.4 show the objective function curve for two PSO-based DTFs and two RFs in the distribution system, respectively. Table 4.6 and Table 4.7 show the optimal values of the DTF and RF which were obtained from the PSO algorithm. The minimum values of the objective function are 0.1085 in the 69 iterations for the DTF and 0.244 in the 84 iterations for the RF.

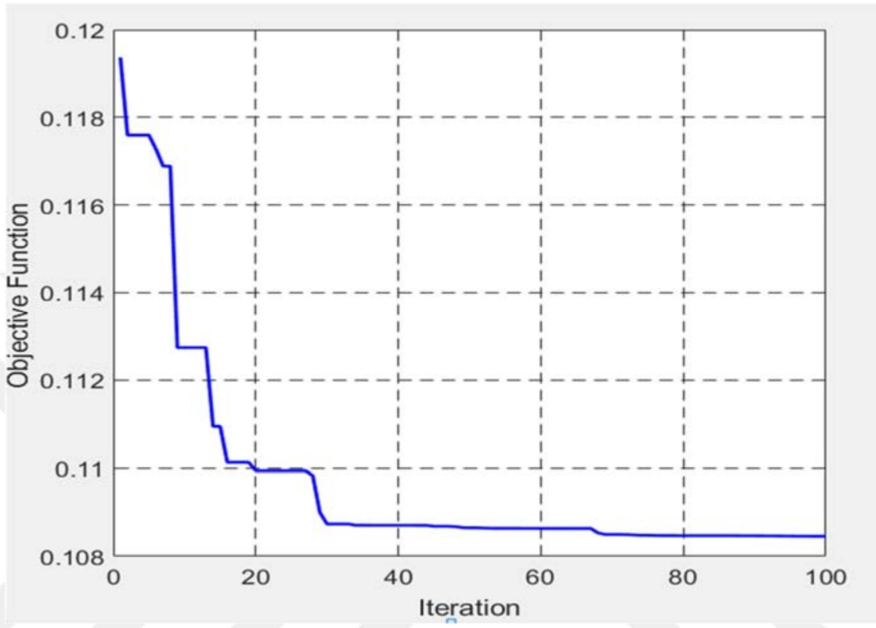


Figure 4.3: Objective function curve of the PSO-based DTF in the Hai Tunis system.

Table 4.5: Optimal values of two DTF parameters in Hai Tunis system.

First DTF Parameters	Values
L1	0.025879mH
C1	11.300 mF
L2	0.298124 μH
C2	9.250 mF
Second DTF Parameters	Values
L1	0.02589 mH
C1	11.0mF
L2	0.280601 μH
C2	1.00 mF

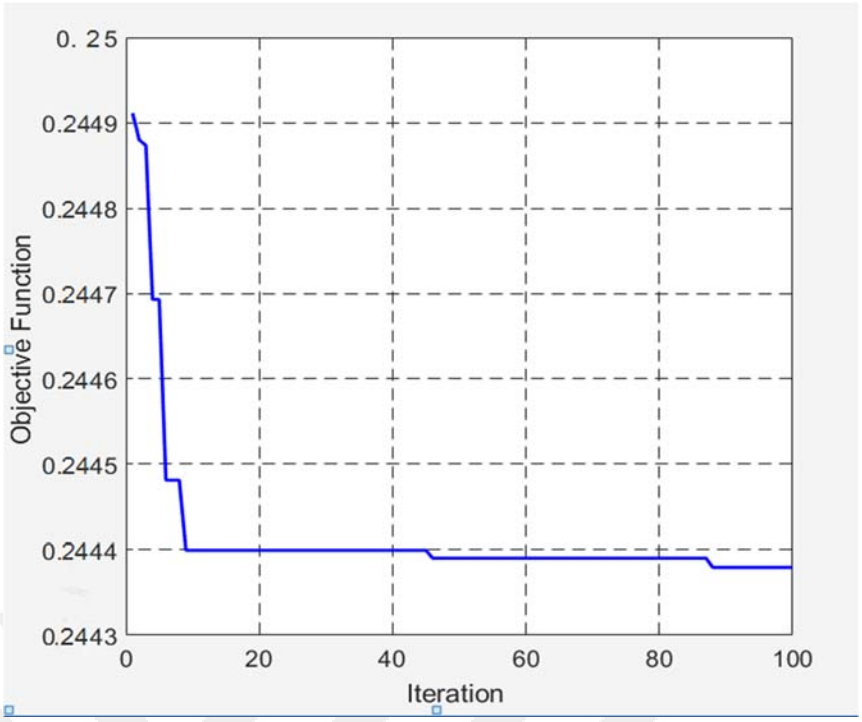


Figure 4.4: Objective function curve of the PSO-based RF in the Hai Tunis system.

Table 4.6: Optimal values of the two RF parameters in the Hai Tunis system.

First RF Parameters	Values
L1	1.10 mH
C1	0.9 F
L2	0.85401 mH
C2	0.0555 F
L3	0.59945 mH
C3	41.9 mF
Second RF Parameters	Values
L1	11 mH
C1	0.879 F
L2	0.78416 mH
C2	0.0557 mF
L3	0.56116 mH
C3	0.0418 mF

4.4 Results of Harmonics Analysis With PSO-based Power Filters

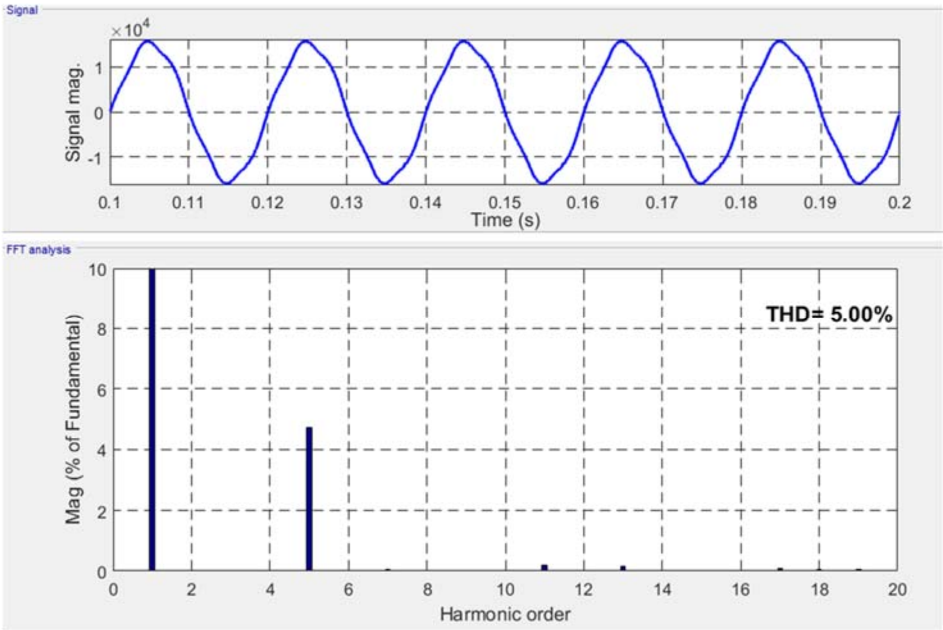
In this work, the proposed PSO-based power filters are applied to the distribution system. The distribution systems is the Iraqi-Hai Tunis distribution system. The proposed algorithm system was designed using a program with the MATLAB software. Validation and testing of the proposed algorithm were carried out through the harmonics analysis for this cases, which is the system before power filter connection and the system after power filter connection. The power filters are PSO-based STF, DTF, and RF, as follows:

4.4.1 Before Power Filter Connection

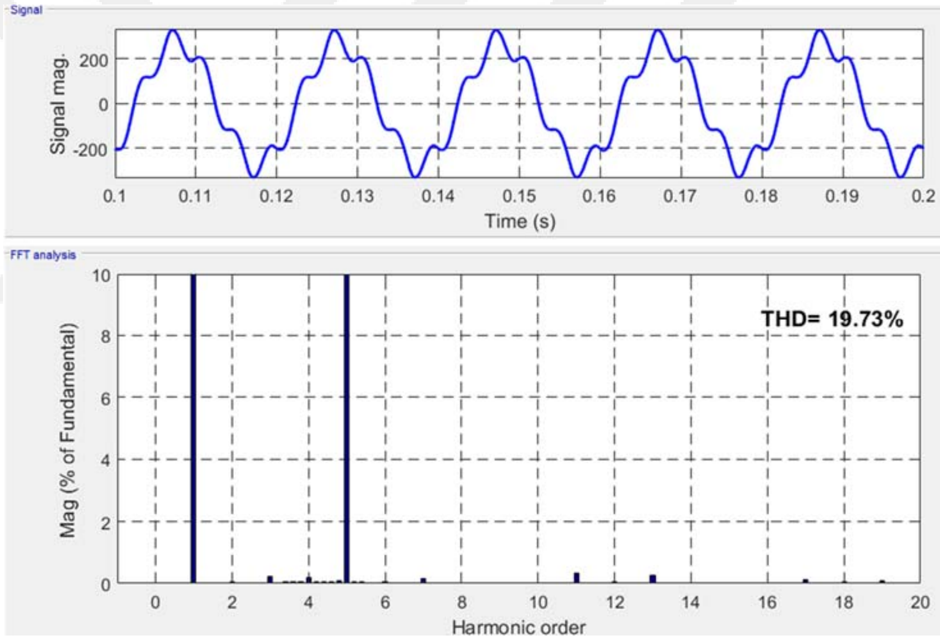
Harmonics analyses are calculated in the distribution systems before power filter connection. The distribution systems was the Iraqi-Hai Tunis distribution system, as follows:

4.4.1.1 Results of the harmonics analysis of the Iraqi-Hai Tunis distribution system

Figure 4.5(a) shows the five cycles of the voltage waveforms and harmonics spectrum of the voltage. Figure 4.5(b) shows the current waveforms and harmonics spectrum of the current in the main feeder in the Iraqi-Hai Tunis distribution system. The fifth harmonic in the voltage and current waveforms are high in value when compared with other harmonics. The THD in the voltages and currents on the main feeder are 5.00% and 19.7%, respectively, as shown in Figure 4.5.



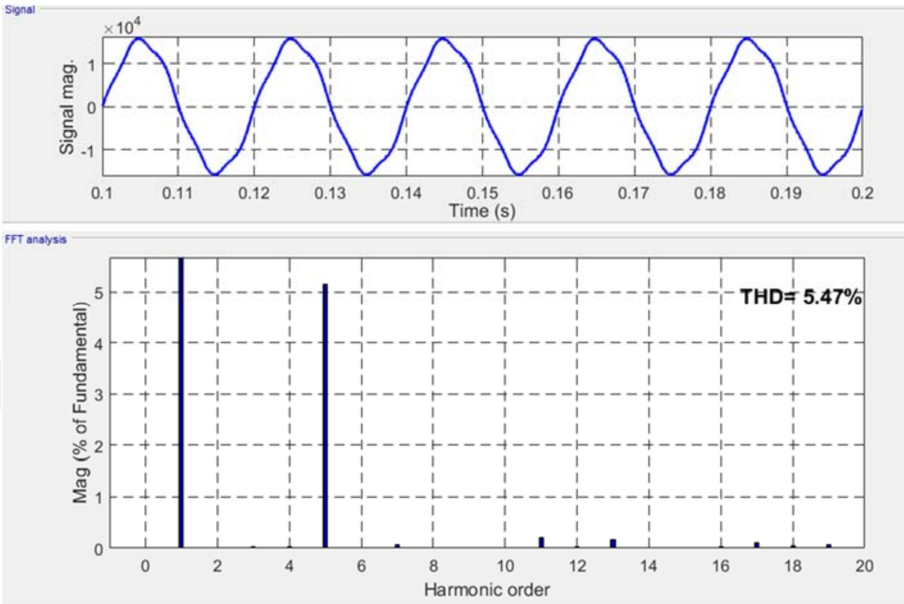
(a)



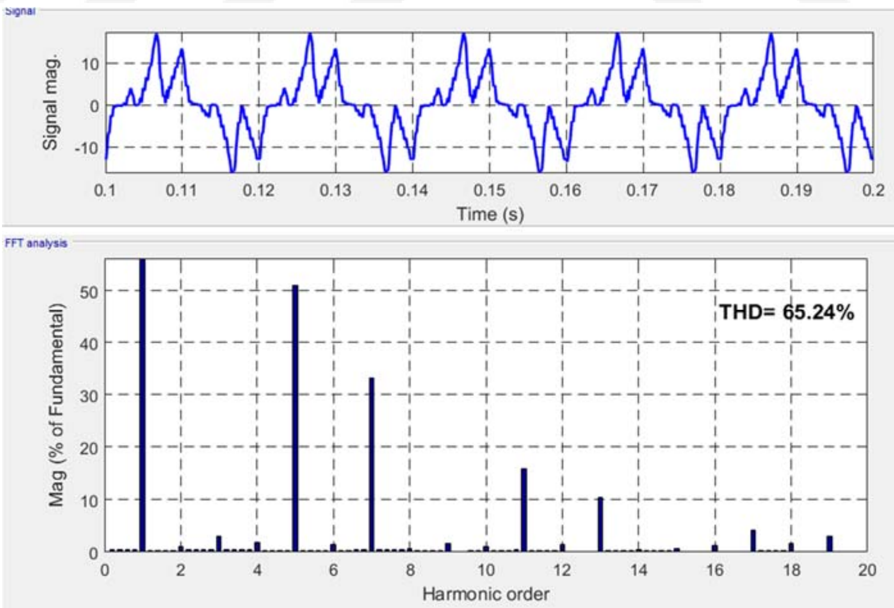
(b)

Figure 4.5: 5 cycle waveforms and harmonics spectrum for the main feeder in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.

Figure 4.6 (a) shows the five cycles of the voltage waveforms and harmonics spectrum of the voltage in Factory-1. Figure 4.6(b) shows the current waveforms and harmonics spectrum of the current in Factory-1 in the Iraqi-Hai Tunis distribution system. The fifth, seventh and eleventh harmonics in the current waveforms are high in value when compared with other harmonics. The THD in the voltage and current in Factory-1 are 5.47% and 65.24%, respectively, as shown in Figure 4.9. Figure 4.7(a) shows the voltage waveforms and harmonics spectrum of the voltage in Factory-2. Figure 4.7(b) shows the current waveforms and harmonics spectrum of the current in Factory-2. The fifth, seventh and eleventh harmonic in the current waveforms are high in value when compared with other harmonics. The THD in the voltage and current in Factory-2 are 5.72% and 65.14%, respectively, as shown in Figure 4.7.

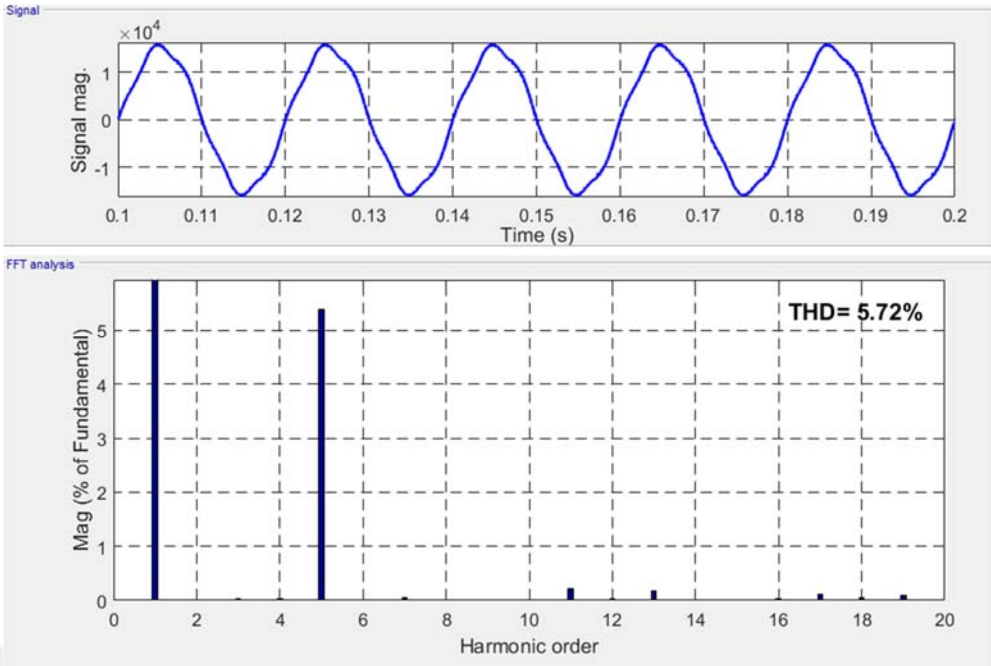


(a)

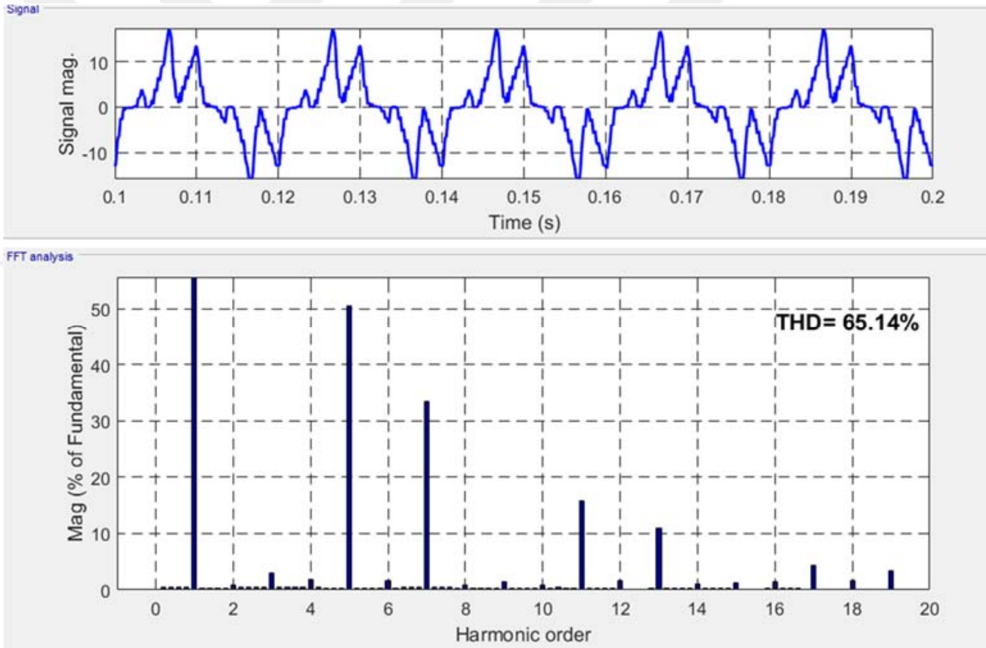


(b)

Figure 4.6: 5 cycles waveforms and harmonics spectrum for Factory-1 in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.



(a)



(b)

Figure 4.7: 5 cycles waveforms and harmonics spectrum for Factory-2 in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.

Table 4.11 shows the total harmonic distortions for the voltages and currents in all buses in the Iraqi-Hai Tunis distribution system before power filter connection. These THDs have increased due to the two factories connecting into the distribution systems.

Table 4.7: THDs for the voltage and current in the all buses before filter connection.

Number of bus	THD_v (%)	THD_i (%)
0	5.00	19.73
1	10.18	24.31
2	8.62	15.45
3	8.61	15.73
4	8.64	15.78
5	8.66	15.71
6	8.75	15.71
7	10.77	25.73
8	9.94	20.54
9	9.94	20.70
10	9.03	16.18
11	10.27	21.33
12	10.26	21.31
13	10.27	21.34
14	10.29	21.36
15	10.46	21.80
16	13.03	35.44
17 (Factory-1)	5.47	65.24
18 (Factory-2)	5.72	65.14

4.4.2 After Optimal Power Filters Connection

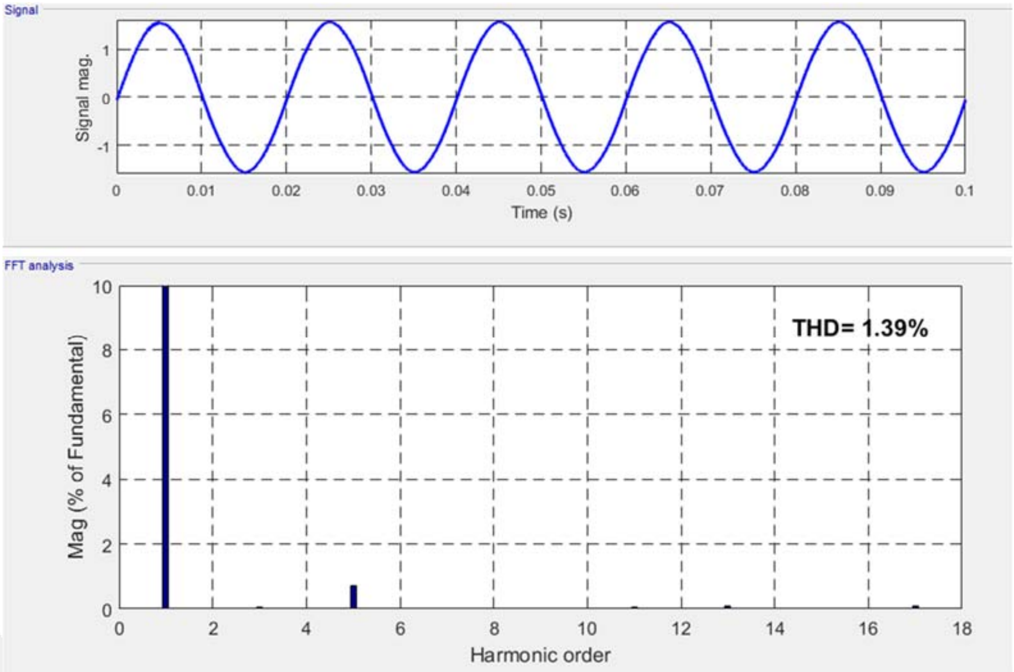
Harmonics analyses are calculated in the distribution systems after optimal filters connection. Optimal power filters improve the STF, DTF, and RF by using the PSO algorithm. The distribution systems is the Iraqi-Hai Tunis distribution system, as follows:

4.4.2.1 Results of the optimal filters in the Iraqi-Hai Tunis distribution system

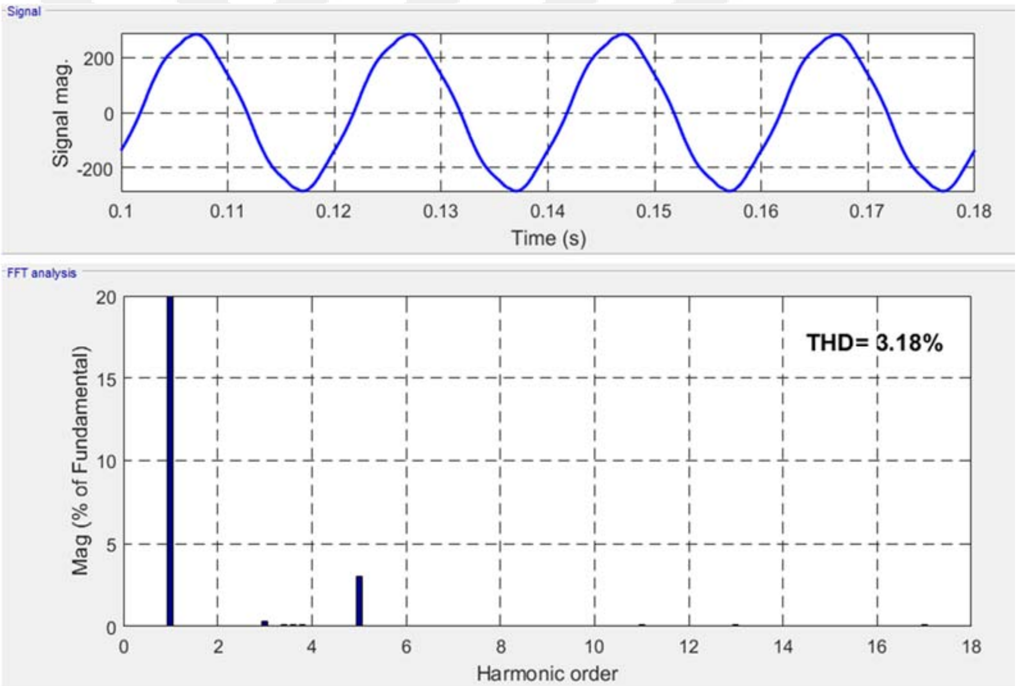
The PSO algorithm is used to improve the power filters, which are the STF, DTF, and RF in the Iraqi-Hai Tunis distribution system. These optimal filters are shown in the following sections:

i. Results of the Optimal STF in the Iraqi-Hai Tunis Distribution System

The results of the PSO-based STF are shown as voltage waveforms and the harmonics spectrum of the voltage is presented in Figure 4.8(a). Figure 4.8(b) shows the current waveforms and harmonics spectrum of the current in the main feeder in the Iraqi-Hai Tunis distribution system. The fifth harmonic in the voltage and current waveforms are removed from the distribution system because of the optimal STF connection in the system. The THD in the voltages and currents on the main feeder are minimized from 5.00% to 1.39% and from 19.7% to 3.18%, respectively, as shown in Figure 4.8.



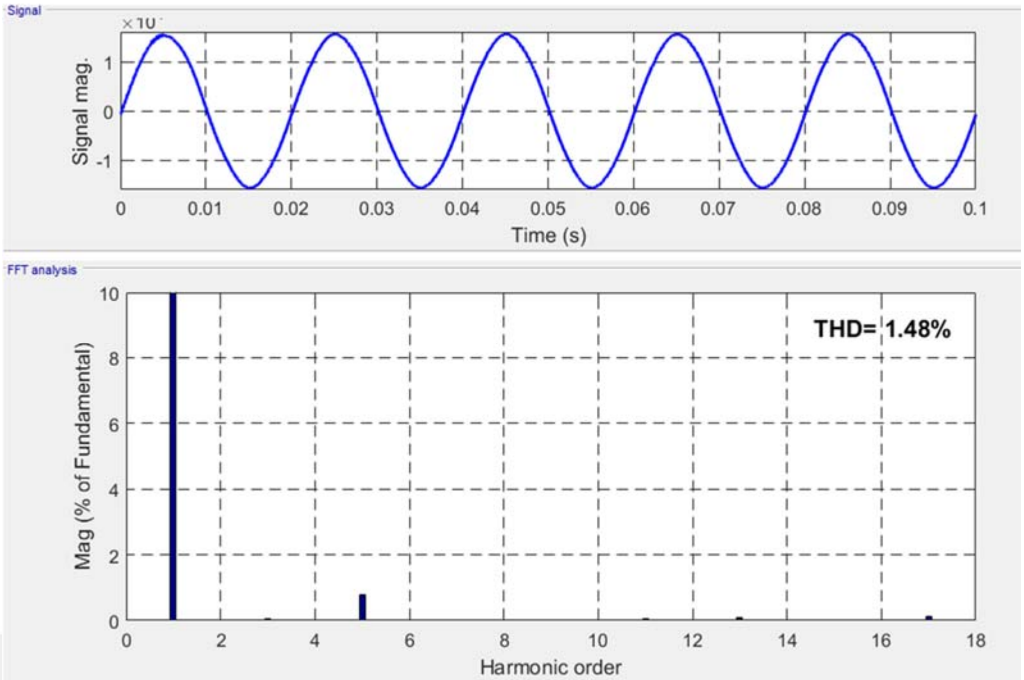
(a)



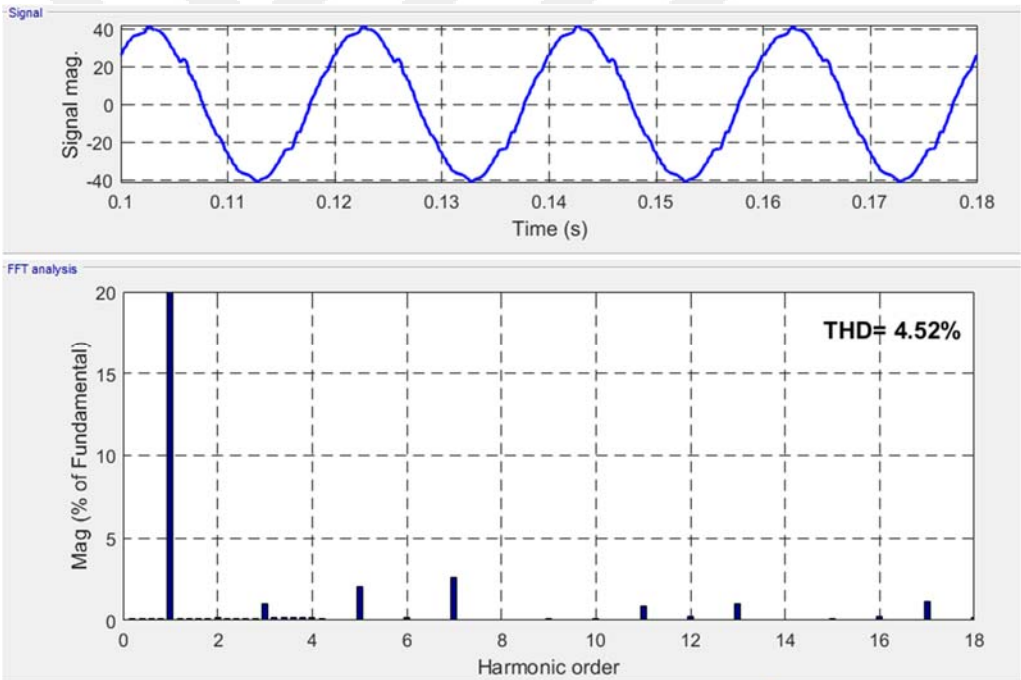
(b)

Figure 4.8: Results of the optimal STF for the waveforms and harmonics spectrum for the main feeder in the Iraqi-Hai Tunis distribution for (a) voltage, and (b) current.

The optimal STF connects the five cycles of the voltage waveforms and harmonics spectrum of the voltage in Factory-1, as shown in Figure 4.9(a). Figure 4.9(b) shows the current waveforms and harmonics spectrum of the current in Factory-1 in the Iraqi-Hai Tunis distribution system. The fifth, seventh and eleventh harmonics in the current waveforms are removed from Factory-1. The THD in the voltage and current in Factory-1 are minimized from 5.47% to 1.48% and from 65.2% to 4.52%, respectively, as shown in Figure 4.15. Figure 4.10(a) shows the voltage waveforms and harmonics spectrum of the voltage in Factory-2. Figure 4.10(b) shows the current waveforms and harmonics spectrum of the current in Factory-2. The fifth, seventh and eleventh harmonics in the current waveforms are removed from the system. The THD in the voltage and current in Factory-2 are minimized from 5.72% to 1.53% and from 65.1% to 4.29%, respectively, as shown in Figure 4.10.

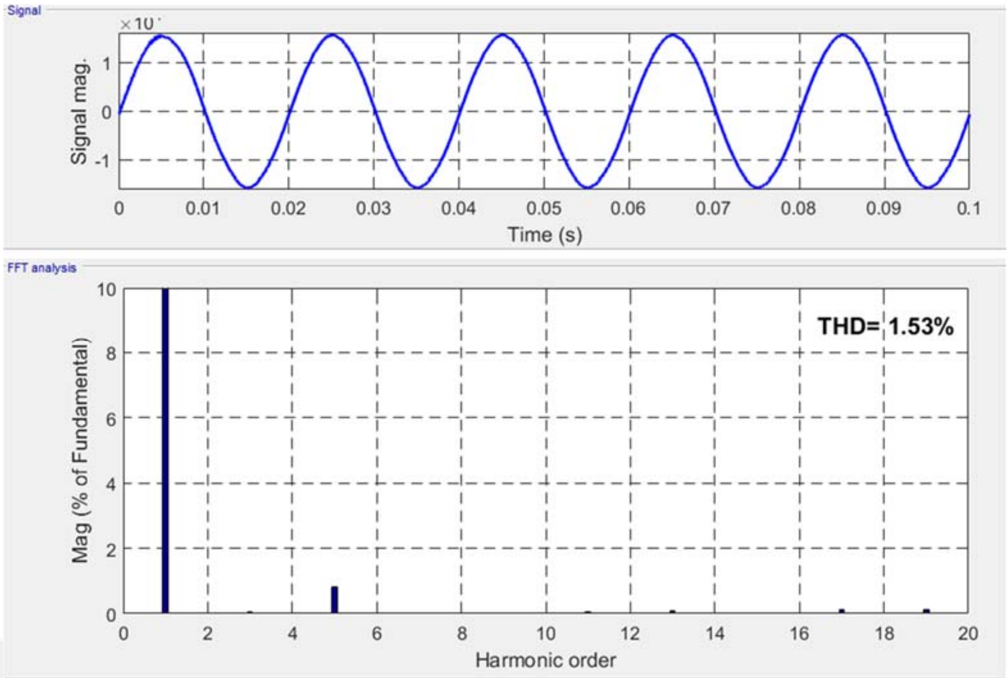


(a)

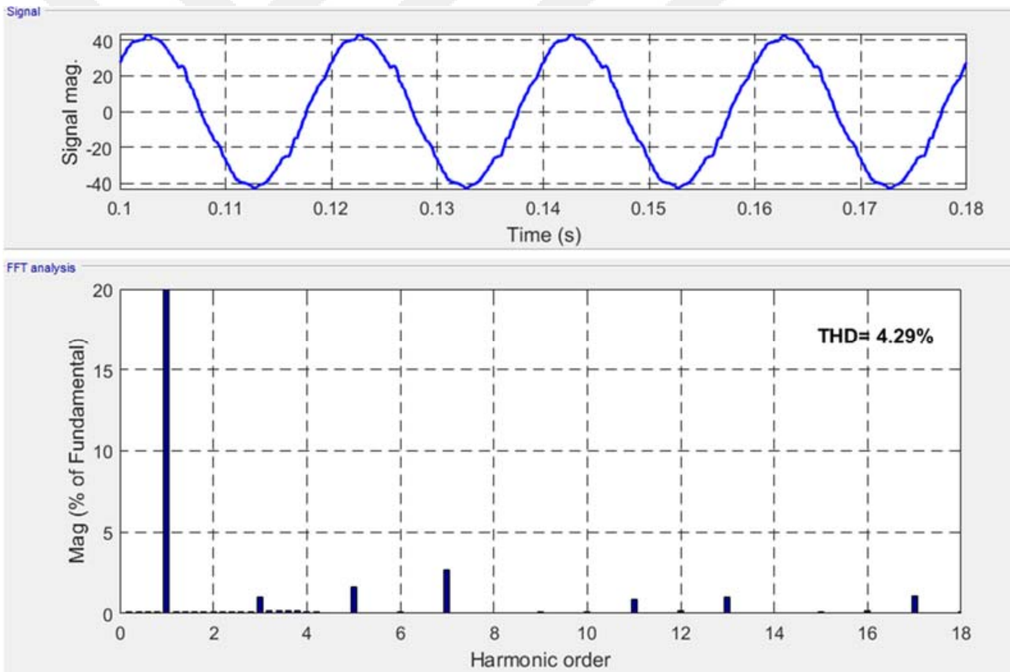


(b)

Figure 4.9: Results of the optimal STF for the waveforms and harmonics spectrum for Factory-1 in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.



(a)



(b)

Figure 4.10: Results of the optimal STF for the waveforms and harmonics spectrum for Factory-2 in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.

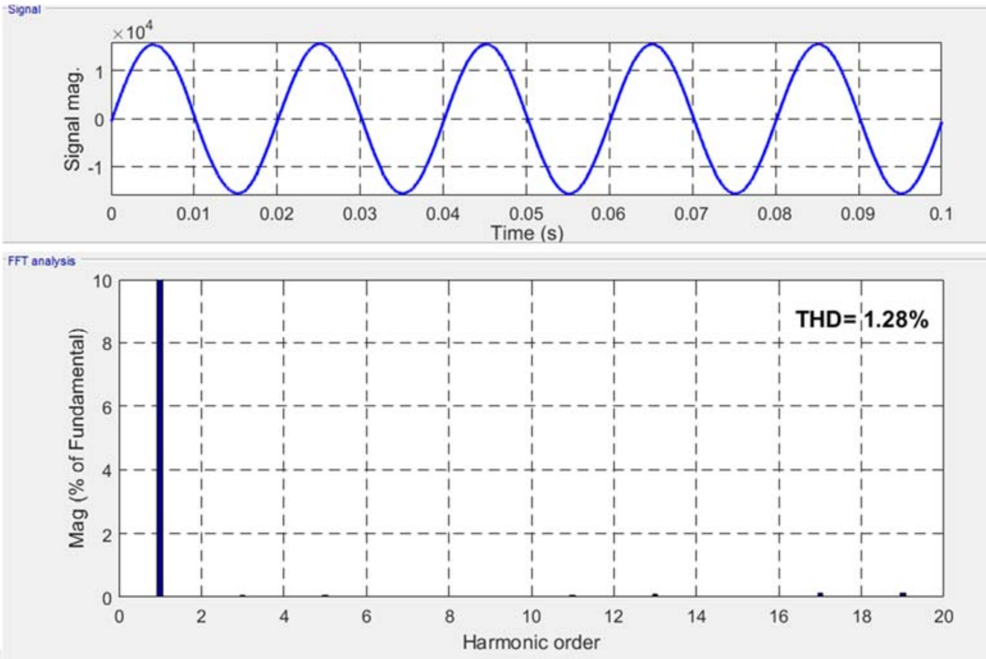
Table 4.8 shows the total harmonics distortion for the voltages and currents in all buses in the Iraqi-Hai Tunis distribution system after optimal SFT connection.

Table 4.8: THDs for the voltages and currents in the all buses after optimal STF connection.

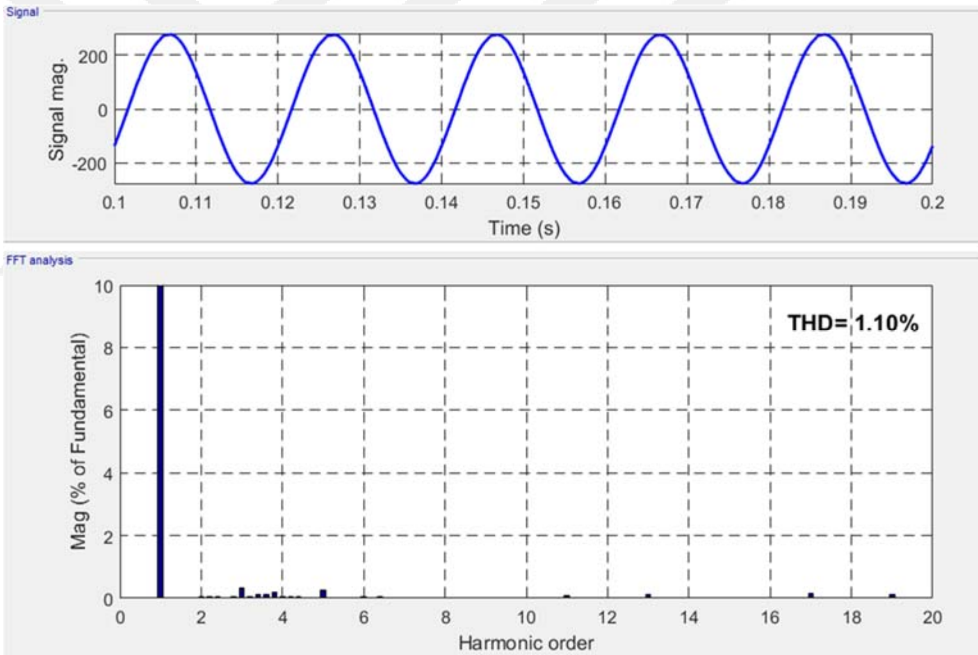
Number of bus	THD_v (%)	THD_i (%)
0	1.39	3.18
1	1.79	3.87
2	1.60	2.61
3	1.60	2.66
4	1.61	2.68
5	1.61	2.69
6	1.62	2.68
7	1.88	4.11
8	1.79	3.62
9	1.83	3.67
10	1.64	2.70
11	1.85	3.68
12	1.85	3.69
13	1.85	3.69
14	1.85	3.69
15	1.89	3.82
16	2.16	5.45
17 (Factory-1)	1.48	4.52
18 (Factory-2)	1.53	4.29

ii. Results of the Optimal DTF in the Iraqi-Hai Tunis Distribution System

Results of the PSO-based DTF are shown by the voltage waveforms and harmonics spectrum of voltage, as in Figure 4.11(a). Figure 4.11(b) shows the current waveforms and harmonics spectrum of the current in the main feeder in the Iraqi-Hai Tunis distribution system. The fifth harmonic in the voltage and current waveforms is removed from the distribution system because of the optimal DTF connection in the system. The THD in the voltages and currents on the main feeder are minimized from 5.00% to 1.28% and from 19.7% to 1.10%, respectively, as shown in Figure 4.11.



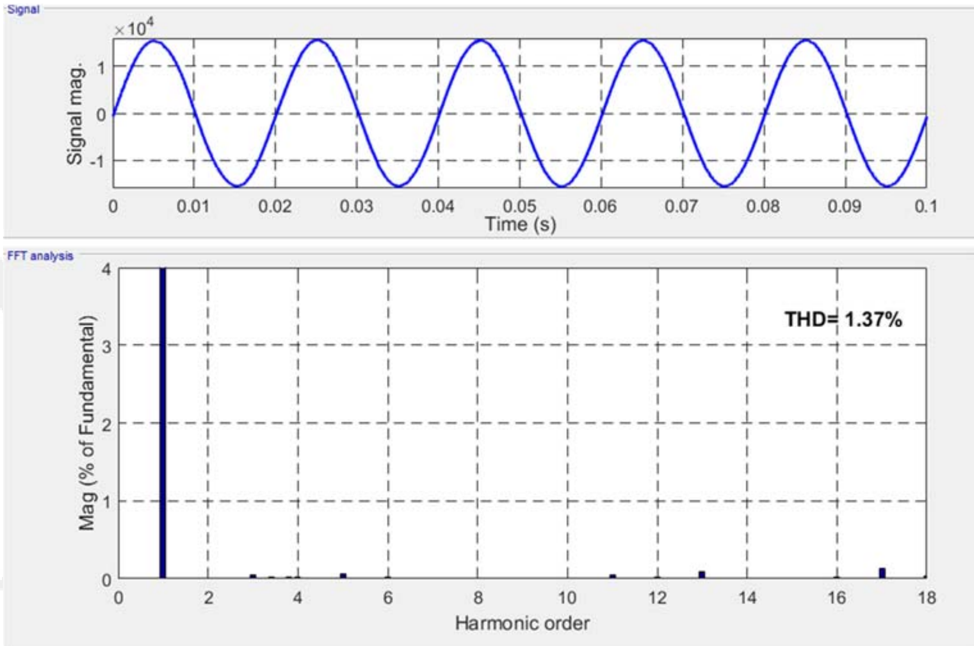
(a)



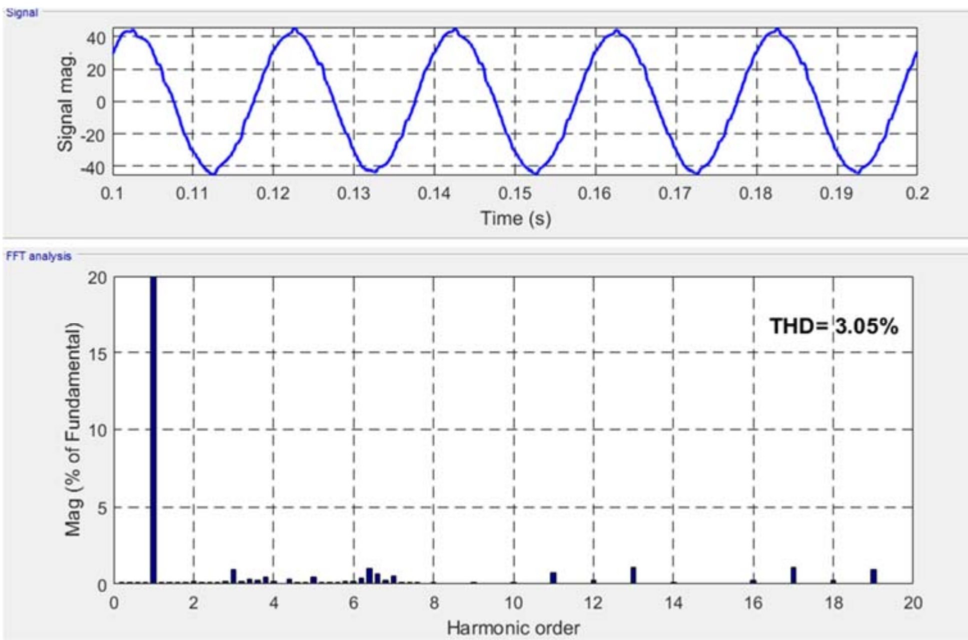
(b)

Figure 4.11: Results of the optimal DTF for waveforms and harmonics spectrum for the main feeder in the Iraqi-Hai Tunis distribution for (a) voltage, and (b) current

Results of the optimal DTF connecting the voltage waveforms and harmonics spectrum of the voltage in Factory-1 are shown in Figure 4.12(a). Figure 4.12(b) shows the current waveforms and harmonics spectrum of the current on Factory-1 in the Iraqi-Hai Tunis distribution system. The fifth, seventh and eleventh harmonics in the current waveforms are removed from Factory-1. The THD in the voltage and current in Factory-1 are minimized from 5.47% to 1.37% and from 65.24% to 3.05%, respectively, as shown in Figure 4.12. Figure 4.13(a) shows the voltage waveforms and harmonics spectrum of the voltage in Factory-2. Figure 4.13(b) shows the current waveforms and harmonics spectrum of the current in Factory-2. The fifth, seventh and eleventh harmonics in the current waveforms are removed from the system. The THD in the voltage and current in Factory-2 are minimized from 5.72% to 1.41% and from 65.14% to 3.15%, respectively, as shown in Figure 4.13.

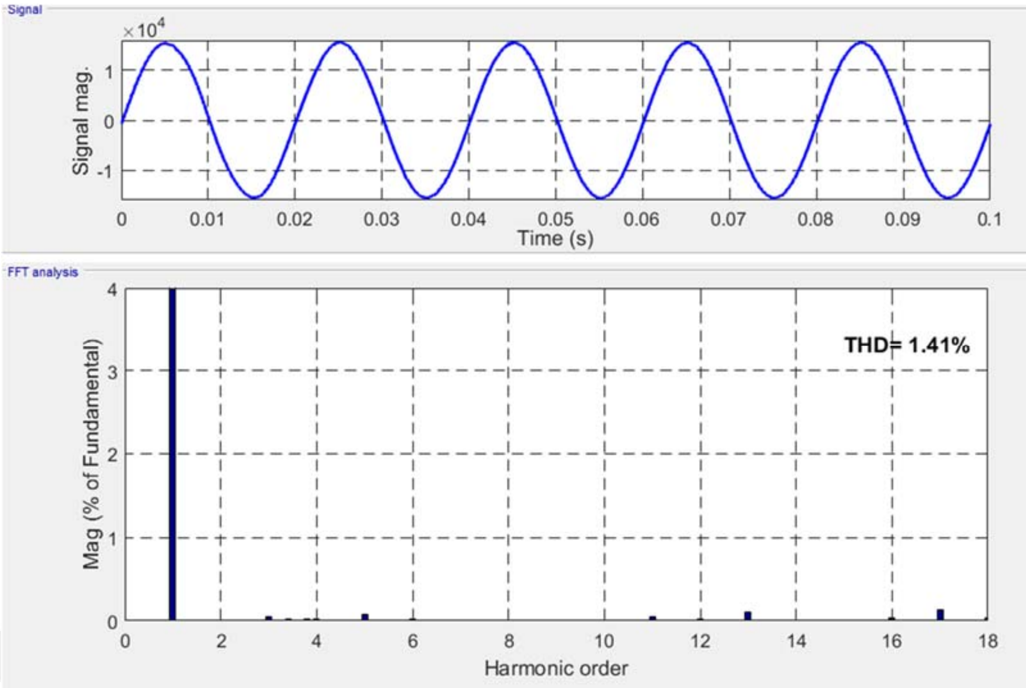


(a)

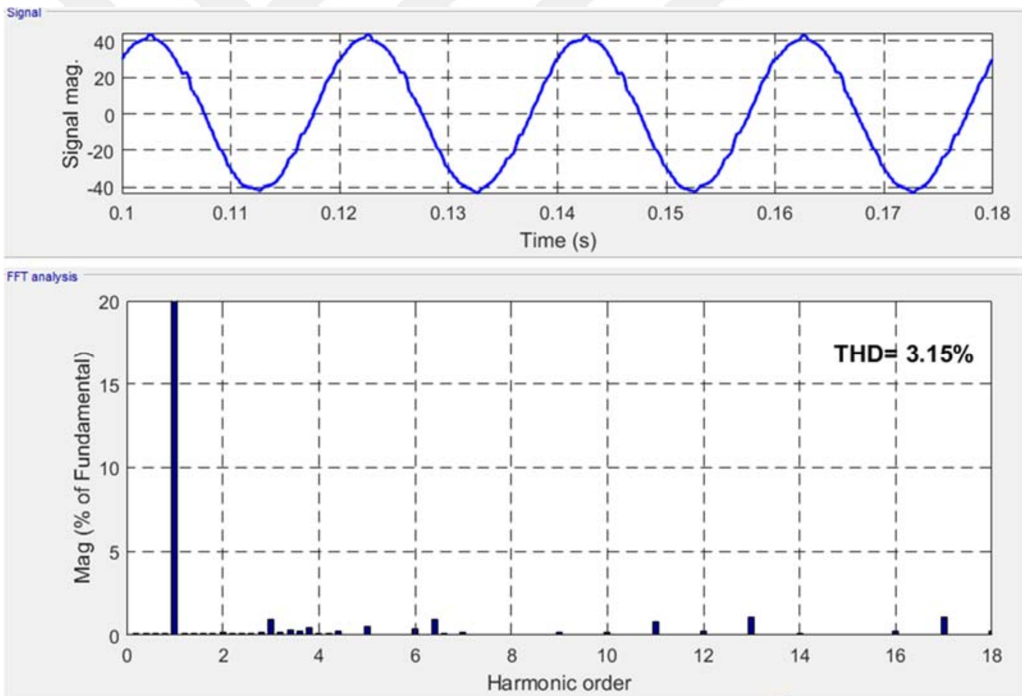


(b)

Figure 4.12: Results of the optimal DTF for the waveforms and harmonics spectrum for Factory-1- in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.



(a)



(b)

Figure 4.13: Results of the optimal DTF for the waveforms and harmonics spectrum for Factory-2 in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.

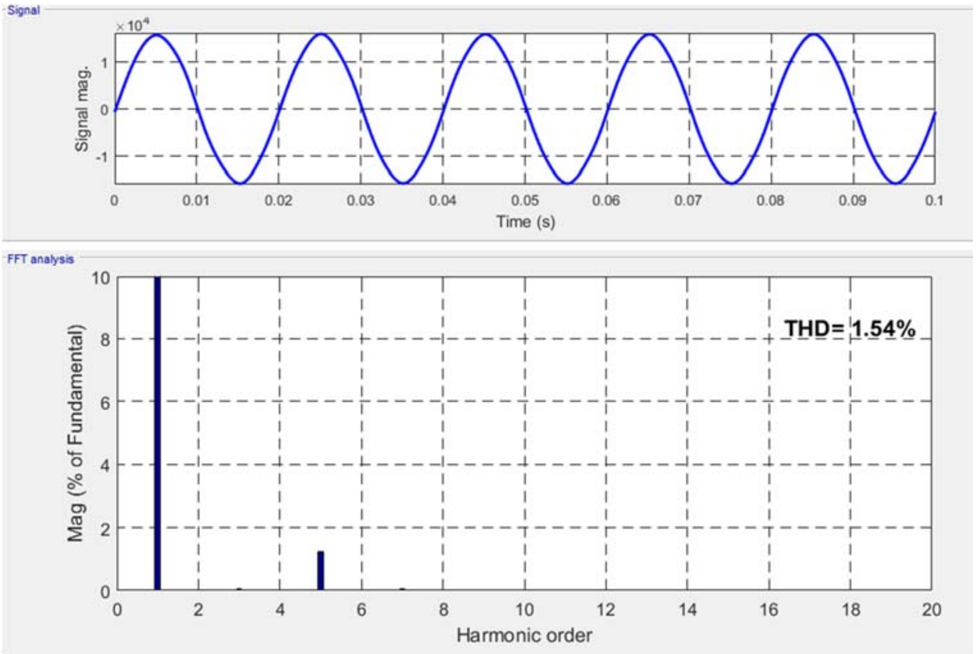
Table 4.9 shows the total harmonics distortion for the voltage and currents in all buses in the Iraqi-Hai Tunis distribution system after optimal DTF connection.

Table 4.9: THDs for voltage and current in the all buses with optimal DTF connection.

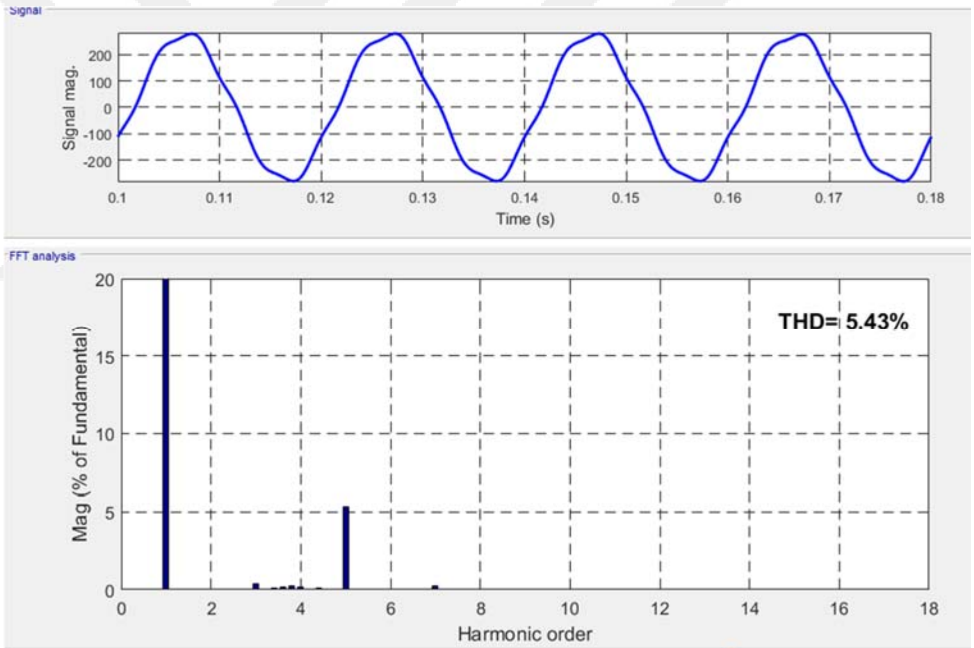
Number of bus	THD_v (%)	THD_i (%)
0	1.28	1.10
1	0.94	1.32
2	0.92	1.05
3	0.92	1.06
4	0.92	1.06
5	0.92	1.07
6	0.92	1.06
7	0.95	1.4
8	0.92	1.11
9	0.92	1.11
10	0.92	1.06
11	0.92	1.07
12	0.92	1.07
13	0.92	1.07
14	0.92	1.07
15	0.92	1.09
16	0.94	1.29
17 (Factory-1)	1.37	3.05
18 (Factory-2)	1.41	3.15

iii. Results of Optimal RF in the Iraqi-Hai Tunis Distribution System

The results of the PSO-based RF are shown as voltage waveforms and a harmonics spectrum of voltage are presented in Figure 4.14(a). Figure 4.14(b) shows the current waveforms and harmonics spectrum of the current in the main feeder in the Iraqi-Hai Tunis distribution system. The fifth harmonic in the voltage and current waveforms are removed in the distribution system because of the optimal RF connection in the system. The THD in the voltages and currents on the main feeder are minimized from 5.00% to 1.54% and from 19.7% to 5.43%, respectively, as shown in Figure 4.14.



(a)

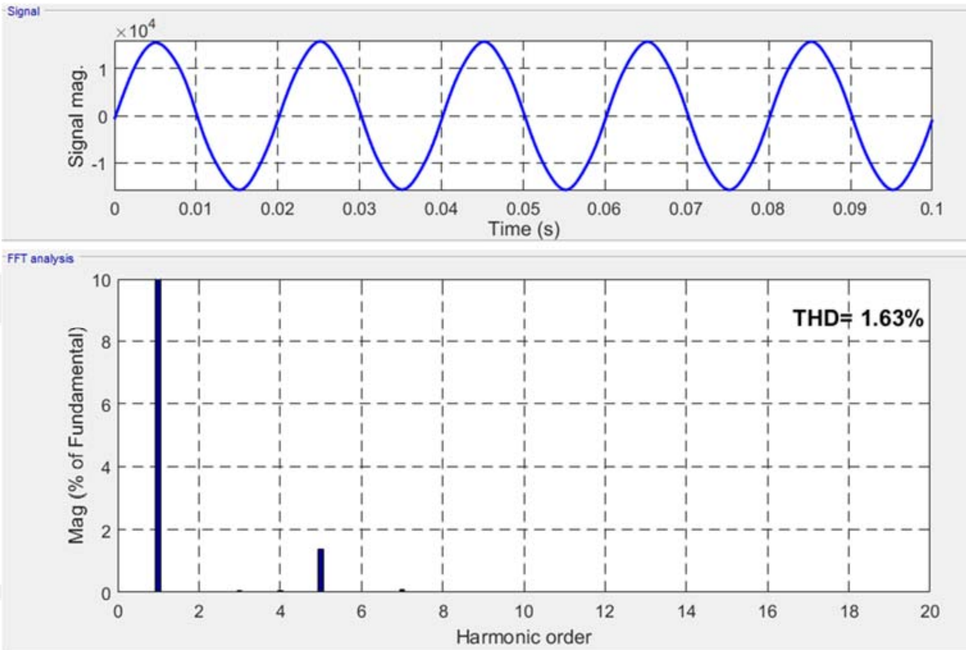


(b)

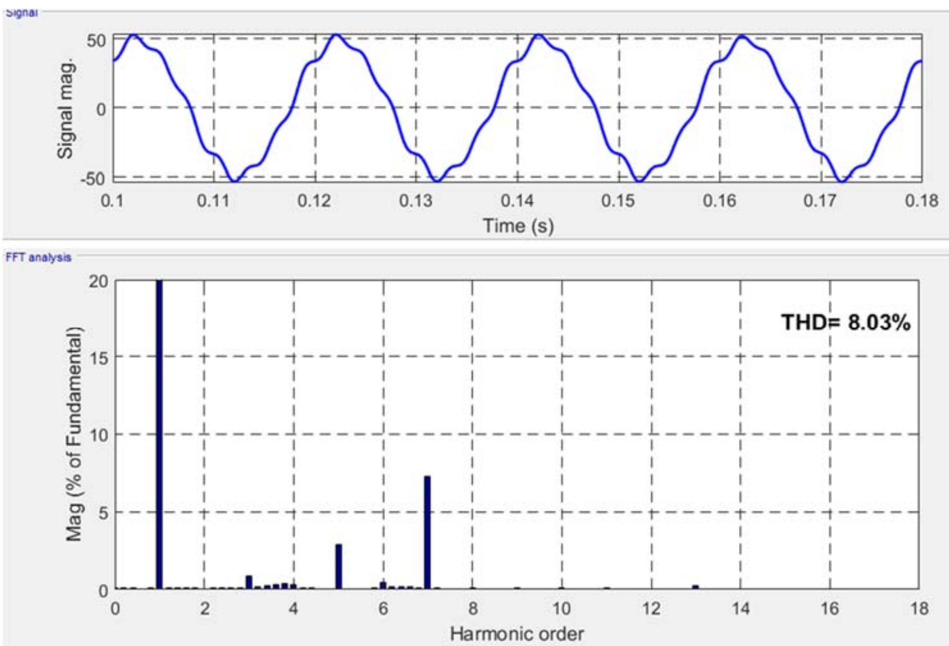
Figure 4.14: Results of the optimal RF for waveforms and the harmonics spectrum for the main feeder in the Iraqi-Hai Tunis distribution for (a) voltage, and (b) current.

The results of the optimal RF connection of the voltage waveforms and harmonics spectrum of the voltage in Factory-1 are shown in Figure 4.15(a). Figure 4.15(b) shows the current waveforms and harmonics spectrum of the current in Factory-1 in the Iraqi-Hai Tunis distribution system. The fifth, seventh and eleventh harmonics in the current waveforms are removed from Factory-1. The THD in the voltage and current in Factory-1 are minimized from 5.42% to 1.63% and from 65.2%

to 8.03%, respectively, as shown in Figure 4.15. Figure 4.16(a) shows the voltage waveforms and harmonics spectrum of the voltage in Factory-2. Figure 4.16(b) shows the current waveforms and harmonics spectrum of the current in Factory-2. The fifth, seventh and eleventh harmonics in the current waveforms are removed from the system. The THD in the voltage and current in Factory-2 are minimized from 5.72% to 1.69% and from 65.14% to 8.35%, respectively, as shown in Figure 4.16.

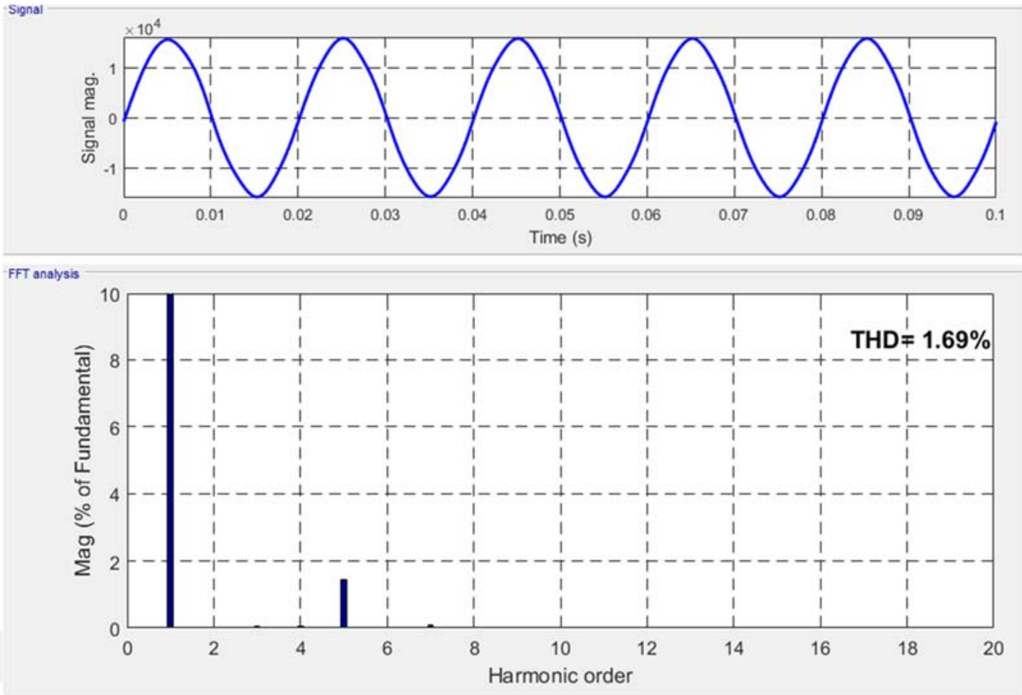


(a)

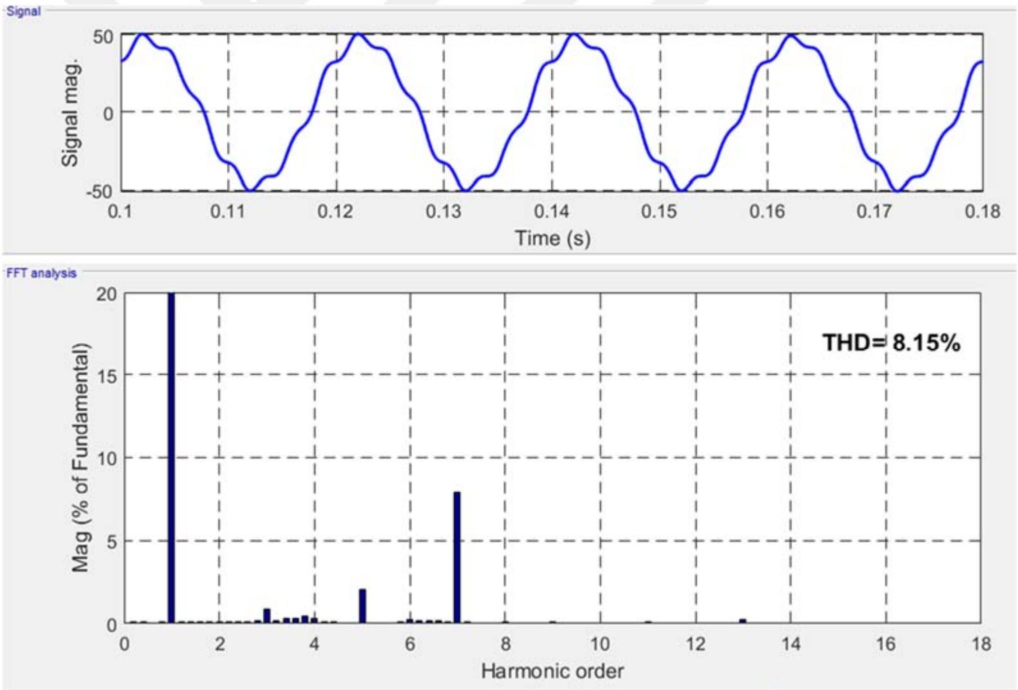


(b)

Figure 4.15: Results of the optimal RF for the waveforms and harmonics spectrum for Factory-1 in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.



(a)



(b)

Figure 4.16: Results of the optimal RF for the waveforms and harmonics spectrum for Factory-2 in the Iraqi-Hai Tunis distribution system for (a) voltage, and (b) current.

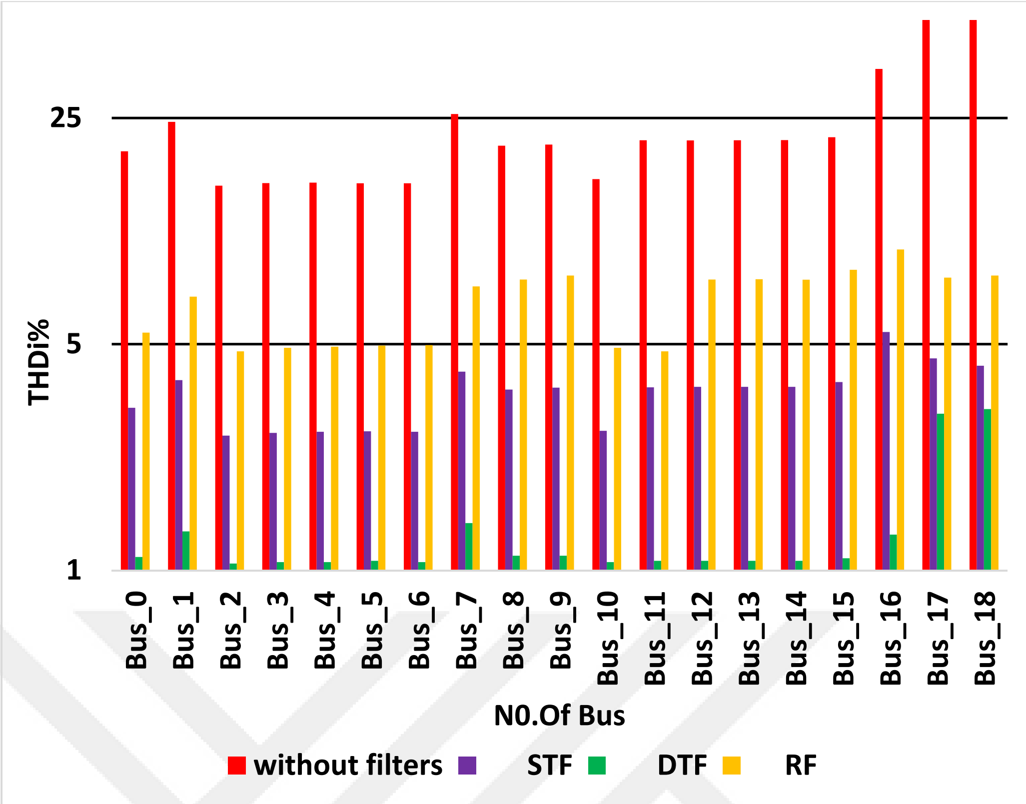
Table 4.10 shows the total harmonics distortion for voltage and currents in all buses in the Iraqi-Hai Tunis distribution system after optimal RF connection. R.F did not attenuate the THDi as shown in the table below.

Table 4.10: THDs for voltage and current in the all buses (optimal RF).

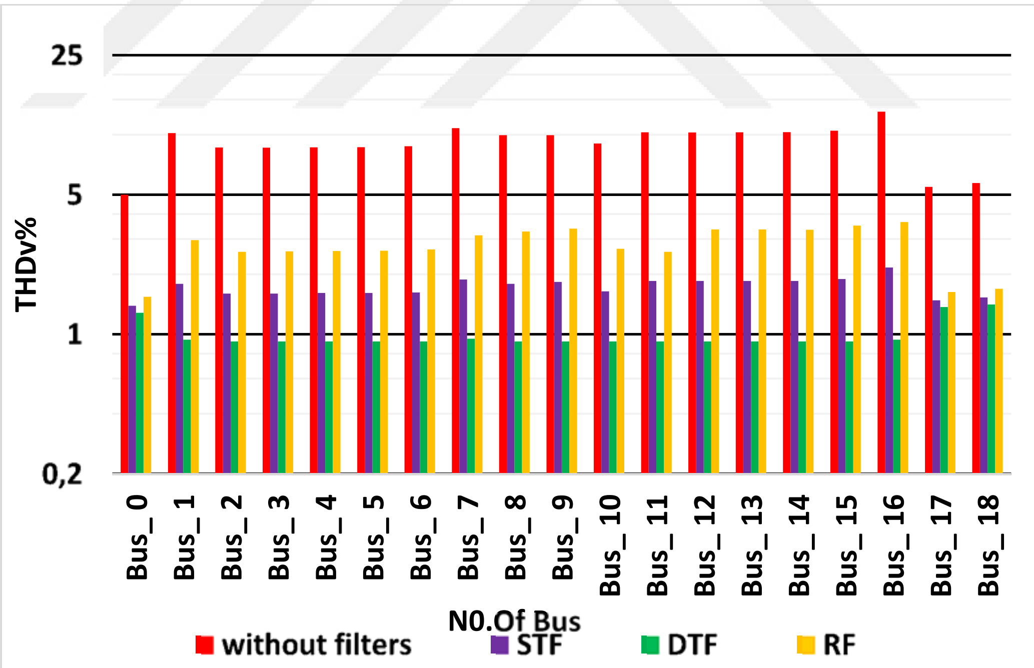
Bus number	THD_v (%)	THD_i (%)
0	1.54	5.43
1	2.96	7.01
2	2.59	4.75
3	2.60	4.87
4	2.61	4.91
5	2.62	4.95
6	2.66	4.97
7	3.13	7.54
8	3.27	7.92
9	3.38	8.15
10	2.68	4.87
11	2.59	4.75
12	3.35	7.92
13	3.35	7.94
14	3.34	7.91
15	3.50	8.49
16	3.65	9.81
17 (Factory-1)	1.63	8.03
18 (Factory-2)	1.69	8.15

4.4.3 Results of the Analysis of the Comparison of Harmonics

Figures 4.17(a) and 4.17(b) show the comparison of the THD voltage and current results between a traditional distribution system and optimal power filters connected to the Iraqi-Hai Tunis distribution system. Optimal DTF in the distribution system achieves the best result by obtaining the minimum values of the THD voltage and current, as shown in Figure 4.17.



(a)



(b)

Figure 4.17: THD of buses for current (a) and voltage (b).

4.4.3 Comparison of Harmonics Analysis Results for Change Loads

Changes in the loads by(+20%) and (–50%)from the rated load occur when the DTF is connected into the system. The THD decreases when increasing the load because the system impedance is decrease, as shown in Table 4.11.

Table 4.11: Effect of THD voltage and current on change loads when DTF is installed in the Iraq-Hai Tunis network.

Number of bus	THD_v (%)			THD_i (%)		
	20% ⬆	Rated	50% ⬇	20% ⬆	Rated	50% ⬇
0	1.28	1.28	1.30	0.98	1.10	1.30
1	0.93	0.94	0.95	1.15	1.32	1.76
2	0.91	0.92	0.92	1.01	1.05	1.56
3	0.91	0.92	0.92	1.02	1.06	1.57
4	0.91	0.92	0.93	1.02	1.06	1.57
5	0.91	0.92	0.93	1.02	1.07	1.58
6	0.91	0.92	0.93	1.02	1.06	1.59
7	0.95	0.95	0.96	1.25	1.4	1.84
8	0.92	0.92	0.93	1.05	1.11	1.61
9	0.92	0.92	0.93	1.05	1.11	1.54
10	0.76	0.92	0.92	0.91	1.06	1.53
11	0.92	0.92	0.92	1.03	1.07	1.53
12	0.92	0.92	0.92	1.03	1.07	1.53
13	0.92	0.92	0.92	1.03	1.07	1.53
14	0.92	0.92	0.92	1.48	1.07	1.53
15	0.92	0.92	0.93	1.05	1.09	1.58
16	0.93	0.94	0.96	1.11	1.29	1.89
17 (constant)	1.43	1.37	1.39	3.09	3.05	3.12
18 (constant)	1.37	1.41	1.44	3.02	3.15	3.08

4.4.4 Power Factor Results

Another objective of this thesis is to improve and develop the power factors through the optimal power filters. The passive filter operates on the improvement of the power factor, which are without filters, optimal STF, optimal DTF and optimal RF. The optimal DTF achieved the improvement of power factors, and the optimal RF almost results from it. Figure 4.18 shows the measurement of the power factor on the main feeder and also presents the optimal DTF with better results from the STR.

The (P.F) and (THD) equations:

$$S(KVA) = Irms \times Vrms = \sqrt[2]{p^2 + Q^2 + D^2} \quad (4.1)$$

Where,

$S = kVA(\ Apparent\ Power)$

$p = kw(Real\ power)$

$Q = kVar(Reactive\ power)$

$D = kVA_h(Distrotion\ \ power)$

Total Power Factor: $$COS\ \emptyset_{TPF} = COS\ \emptyset_{disPF} \times COS\ \emptyset_{distPF} \quad (4.2)$$

Displacement Power Factor: $$COS\ \emptyset_{disPF} = \frac{KW}{KVA\ (fundamental)} \quad (4.3)$$

Distortion Power Factor: $$COS\ \emptyset_{distPF} = \frac{1}{\sqrt[2]{(1+TH\ D^2)\times(1+THD^2)}} \quad (4.4)$$

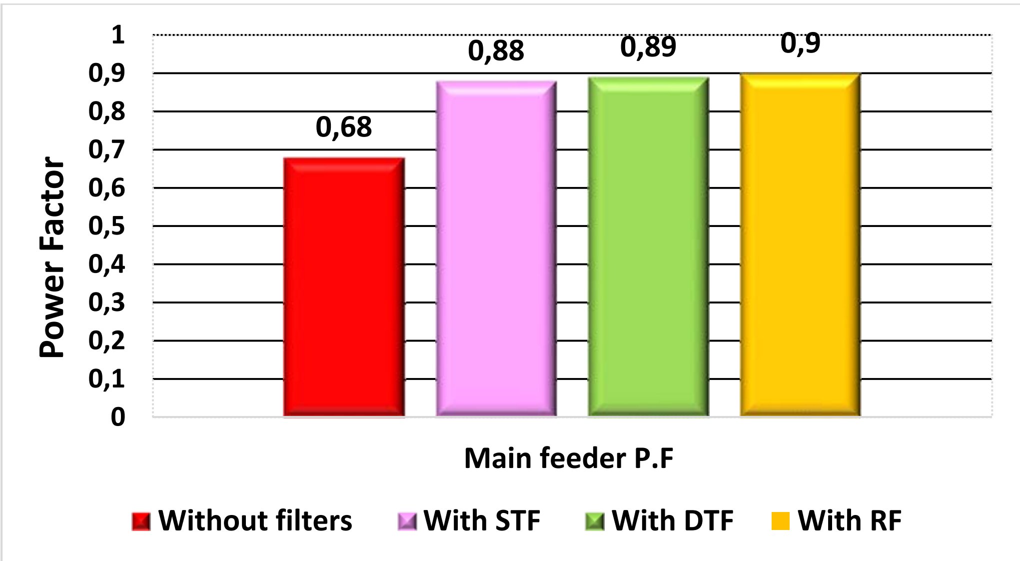


Figure 4.18: Power factor on the main feeder for all cases

4.4.5 Comparison of Harmonics Analysis Results for Change Parameters Filter

Change in the parameters fitter by (+50%) and (-50%) from the optimal (L and C) values when DTF connected in the system. The THD current and voltage increased when deviating from the optimal values which obtained from the proposed algorithm as shown in table 4.12.

Table 4.12: shows the effect of THDs voltage and current for change filter parameters when DFT installed in Iraq Hai Tunis network.

Number of bus	THD_v (%)			THD_i (%)		
	+50%	DTF	-50%	+50%	DTF	-50%
0	1.30	1.28	3.10	2.04	1.10	12.2
1	1.40	0.94	6.30	3.00	1.32	15.4
2	1.30	0.92	5.54	2.10	1.10	10.7
3	1.30	0.92	5.60	2.11	1.10	11.1
4	1.30	0.92	5.62	2.13	1.10	11.2
5	1.30	0.92	5.70	2.20	1.10	11.3
6	1.30	0.92	5.80	2.20	1.10	11.4
7	1.41	0.95	6.70	3.00	1.40	16.8
8	1.53	0.92	7.20	3.40	1.11	18.1
9	1.60	0.92	7.40	3.52	1.11	18.6
10	1.30	0.92	5.70	2.10	1.10	10.8
11	1.50	0.92	7.60	3.30	1.10	18.4
12	1.50	0.92	7.60	3.30	1.10	18.4
13	1.50	0.92	7.60	3.30	1.10	18.4
14	1.50	0.92	7.60	3.24	1.10	18.4
15	1.60	0.92	7.80	3.54	1.10	19.1
16	1.54	0.94	7.80	3.54	1.30	21.3
17	1.40	1.37	3.40	3.43	3.10	49.6
18	1.43	1.41	3.51	3.60	3.20	41.3

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORKS

5.1 Conclusions

The purpose of this study is to find the optimum method to minimize the harmonics in the distribution systems using particle swarm optimization (PSO) algorithm. In this thesis, the proposed algorithm model has been applied onto the Iraqi-Hai Tunis distribution system. The conclusion for this thesis is summarized as follows:

Many passive filters were applied to improve the distribution systems through minimizing the total harmonics factors for voltage and current. The results of the THD (for voltages and currents) in the main feeder of Iraqi-Hai Tunis distribution system were (5.00%) and (19.7%) before connecting the optimal filter, (1.39%) and (3.18%) for optimal STF, (1.01%) and (1.18%) for optimal DTF and (1.54%) and (5.43%) for optimal RF. Therefore, simulation results proved the PSO-based DTF is the most efficient compared to the PSO-based STF and PSO-based RF, as it minimized the harmonics of voltage and current in the Iraqi-Hai Tunis distribution system. The PSO-based DTF resulted in a low level harmonics in the IEEE 519-1992 Standard for voltage and current waveforms. The results of PSO-based STF and PSO-based RF achieved a low level of harmonics in some of the buses of the distribution systems.

Iraqi-Hai Tunis distribution system is developed and designed by actual values of the distribution components such as transformers, distribution lines, capacitors and loads. In this thesis, the actual distribution was applied by MATLAB/SIMULINK to simulate as the real systems. The simulation systems have advantages such as, the measurements and displaying of the power flow such as voltage, current and total harmonics distortions are easy to obtain.

5.2 Suggestions for Future Works

In this thesis, the PSO-based power filters develop and improve the distribution systems. Furthermore, the proposed algorithm could be developed as an iterative technique with security constraints. The following points can be considered for future studies.

Another optimization algorithm can be used and implemented to achieve better results, such as ant colony algorithm (ACA), gravitation search algorithm (GSA), backtracking search algorithm (BSA), and intelligent algorithm (AI). the proposed algorithm can be used in other passive or active filters to find the optimum filters suitable for the distribution systems.

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APPENDIX

Appendix-A: Transformer details 250 KVA

ASTOR	ASTOR A.Ş. TRANSFORMER TEST REPORT					DATE	19.7.2017
TYPE	Hermetic	Windings (HV/LV)	Cu/Cu	T. Rise Oil/Wind. (K)	45 / 50	BRAND	ASTOR
POWER	250 kVA	3 PHASE (50Hz)		VECTOR GROUP	Dyn11	SERIAL NO.	17-06997

Tab	Primary V. (V)	Secondary V. (V)	Primary C. (A)	Secondary C. (A)
1	10450			
2	10725			
3	11000	416/240	13,122	346,965
4	11275			
5	11550			

DC WINDING RESISTANCES t(°C) = 27,8					
HV Winding (Ω)			LV Windings (mΩ)		
R_{1U1V}	:	4,6500	R_{2U2V}	:	5,0980
R_{1V1W}	:	4,6280	R_{2V2W}	:	5,0780
R_{1W1U}	:	4,6070	R_{2W2U}	:	5,1100
R_{1ORT}	:	4,6283	R_{2ORT}	:	5,0953
Deviation	:	0,933%	Deviation	:	0,630%

Tab	Nominal Values	TURN RATIO			DEVIATION (≤ %0,5)		
		1U1V/2U2N	1V1W/2V2N	1W1U/2W2N	1U1V/2U2N	1V1W/2V2N	1W1U/2W2N
1	43,51	43,50	43,50	43,50	0,019	0,017	0,017
2	44,65	44,64	44,64	44,64	0,026	0,023	0,023
3	45,80	45,79	45,79	45,79	0,031	0,029	0,029
4	46,94	46,93	46,93	46,93	0,037	0,035	0,035
5	48,09	48,07	48,07	48,07	0,040	0,038	0,036

INSULATION RESISTANCES (GΩ)					20 °C	
Time	15 s	30 s	45 s	60s	30 s	60 s
HV - Tank (5 kVdc)	-	72	-	86	123,3	147,1
HV - LV (5 kVdc)	-	65	-	87	111,8	149,3
LV - Tank (2,5 kVdc)	-	26	-	31	45,1	53,8

DIELECTRIC TESTS			
TEST NAME	Voltage	Frequency	Time
APLIED POTENTIAL HV	28 kV	50 Hz	60 s
APLIED POTENTIAL LV	3 kV	50 Hz	60 s
INDUCED AC WITHSTAND	0,83 kV	150 Hz	40 s

MEASUREMENT OF SHORT CIRCUIT IMPEDANCE & LOAD LOSSES					
NOMINAL VOLTAGE (V)		MULTIPLIER		WATTMETER (W)	
11000		W.	1	1	698,5
CURRENT (A)	13,122	V.T.	1	2	754,6
U_k (V)	476	C.T.	1	3	793,5

MEASUREMENT OF NO-LOAD LOSS AND CURRENTS					
MULTIPLIER		CURRENT (A)		WATTMETER (W)	
W.	1	2U	5,0798	1	362
V.T.	1	2V	4,3135	2	102,3
C.T.	1	2W	5,3788	3	139,3

CALCULATED VALUES	NO-LOAD LOSSES (P_0) Tol.=+%0 (W)	NO LOAD CURRENT (I_0) Tol.=+%30 (%)	LOAD LOSSES @ 75°C (Pk) Tol.=+%0 (W)	S.C. IMPEDANCE @ 75°C (Uk) Tol.=±%10 (%)	VOLTAGE REGULATION @ 4/4 LOAD cosØ = 1	EFFICIENCY @ 4/4 LOAD (η) cosØ = 1
GUARANTEED	650	1,6	2750	4,3	(%)	(%)
RESULTS	604	1,42	2594	4,36	1,13	98,74

Oil Type	Oil Weight(kg)	Active Part Weight (kg)	Total Weight (kg)
SHELL DIALA B	135	640	860

This transformer meets requirements provided by IEC 60076 standards.

TPI

Witnessed

Reviewed

TURKEY Date 13.07./2017

Approved

Prj.No.17-199-90

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FRM-39/00

Transformer details 400 KVA

ASTOR	ASTOR A.Ş. TRANSFORMER TEST REPORT					DATE	19.8.2017
TYPE	Hermetic	Windings (HV/LV)	Cu/Cu	T. Rise Oil/Wind. (K)	45 / 50	BRAND	ASTOR
POWER	400 kVA	3 PHASE (50Hz)		VECTOR GROUP	Dyn11	SERIAL NO.	17-6068

Tab	Primary V. (V)	Secondary V. (V)	Primary C. (A)	Secondary C. (A)
1	10450			
2	10725			
3	11000	416/240	20,995	555,144
4	11275			
5	11550			

DC WINDING RESISTANCES t(°C) = 27					
HV Winding (Ω)			LV Windings (mΩ)		
R_{1U1V}	:	2,5180	R_{2U2V}	:	2,5640
R_{1V1W}	:	2,5080	R_{2V2W}	:	2,5630
R_{1W1U}	:	2,5030	R_{2W2U}	:	2,5940
R_{1ORT}	:	2,5097	R_{2ORT}	:	2,5737
Deviation	:	0,599%	Deviation	:	1,210%

Tab	Nominal Values	TURN RATIO			DEVIATION (≤ %0,5)		
		1U1V/2U2N	1V1W/2V2N	1W1U/2W2N	1U1V/2U2N	1V1W/2V2N	1W1U/2W2N
1	43,51	43,53	43,52	43,53	0,038	0,033	0,036
2	44,65	44,67	44,67	44,67	0,030	0,026	0,033
3	45,80	45,81	45,81	45,81	0,023	0,019	0,023
4	46,94	46,95	46,95	46,95	0,016	0,014	0,016
5	48,09	48,10	48,09	48,10	0,012	0,008	0,012

INSULATION RESISTANCES (GΩ)					20 °C	
Time	15 s	30 s	45 s	60s	30 s	60 s
HV - Tank (5 kVdc)	-	28	-	33	**45,3**	**53,1**
HV - LV (5 kVdc)	-	42	-	52	**68,0**	**84,1**
LV - Tank (2,5 kVdc)	-	22	-	28	**35,5**	**46,1**

DIELECTRIC TESTS			
TEST NAME	Voltage	Frequency	Time
APLIED POTENTIAL HV	28 kV	50 Hz	60 s
APLIED POTENTIAL LV	3 kV	50 Hz	60 s
INDUCED AC WITHSTAND	0,83 kV	150 Hz	40 s

MEASUREMENT OF SHORT CIRCUIT IMPEDANCE & LOAD LOSSES					
NOMINAL VOLTAGE (V)		MULTIPLIER		WATTMETER (W)	
11000		W.	1	1	1068,6
CURRENT (A)	20,995	V.T.	1	2	1042
U_k (V)	455	C.T.	1	3	1078,3

MEASUREMENT OF NO-LOAD LOSS AND CURRENTS					
MULTIPLIER		CURRENT (A)		WATTMETER (W)	
W.	1	2U	8,64	1	610,7
V.T.	1	2V	6,67	2	196,8
C.T.	1	2W	8,78	3	72,9

CALCULATED VALUES	NO-LOAD LOSSES (P_0) Tol.=+%0 (W)	NO LOAD CURRENT (I_0) Tol.=+%30 (%)	LOAD LOSSES @ 75°C (Pk) Tol.=+%0 (W)	S.C. IMPEDANCE @ 75°C (Uk) Tol.=+%10 (%)	VOLTAGE REGULATION @ 4/4 LOAD cosØ = 1	EFFICIENCY @ 4/4 LOAD (η) cosØ = 1
GUARANTEED	920	1,4	3775	4,1	(%)	(%)
RESULTS	**880**	**1,37**	**3717**	**4,16**	1,01	98,86

Oil Type	Oil Weight(kg)	Active Part Weight (kg)	Total Weight (kg)
SHELL DIALA B	195	860	1230

This transformer meets requirements provided by IEC 60076 standards.

Customer **Approved**

120 TURKEY Witnessed Reviewed Date 13.08/2017

ASTOR TRANSFORMATÖR ENERJİ TURİZM İNŞAAT ve PETROL SANAYİ TİC. A.Ş. 1. ORGANİZE SANAYİ BÖLGESİ ANADOLU CAD. NO:6 SİNCAN/ANKARA

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FRM-39/00

Transformer details 630 KVA

ASTOR	ASTOR A.Ş. TRANSFORMER TEST REPORT					DATE	28.4.2017
TYPE	Hermetic	Windings (HV/LV)	Cu/Cu	T. Rise Oil/Wind. (K)	45 / 50	BRAND	ASTOR
POWER	630 kVA	3 PHASE (50Hz)		VECTOR GROUP	Dyn11	SERIAL NO.	17-03454

Tab	Primary V. (V)	Secondary V. (V)	Primary C. (A)	Secondary C. (A)
1	10450			
2	10725			
3	11000	416/240	33,066	874,353
4	11275			
5	11550			

DC WINDING RESISTANCES t(°C) = 17,8					
HV Winding (Ω)			LV Windings (mΩ)		
R_{1U1V}	:	1,3049	R_{2U2V}	:	1,3991
R_{1V1W}	:	1,3144	R_{2V2W}	:	1,3956
R_{1W1U}	:	1,3242	R_{2W2U}	:	1,4166
R_{1ORT}	:	1,3145	R_{2ORT}	:	1,4038
Deviation	:	1,479%	Deviation	:	1,505%

Tab	Nominal Values	TURN RATIO			DEVIATION (≤ %0,5)		
		1U1V/2U2N	1V1W/2V2N	1W1U/2W2N	1U1V/2U2N	1V1W/2V2N	1W1U/2W2N
1	43,51	43,51	43,51	43,51	0,001	0,001	0,001
2	44,65	44,63	44,63	44,63	0,055	0,055	0,055
3	45,80	45,83	45,83	45,83	0,067	0,067	0,067
4	46,94	46,94	46,94	46,94	0,009	0,009	0,009
5	48,09	48,07	48,07	48,07	0,040	0,032	0,040

INSULATION RESISTANCES (GΩ)					20 °C	
Time	15 s	30 s	45 s	60s	**30 s**	**60 s**
HV - Tank (5 kVdc)	-	44	-	51	**38,0**	**44,0**
HV - LV (5 kVdc)	-	66	-	75	**56,5**	**64,3**
LV - Tank (2,5 kVdc)	-	24	-	31	**21,0**	**26,4**

DIELECTRIC TESTS			
TEST NAME	Voltage	Frequency	Time
APLIED POTENTIAL HV	28 kV	50 Hz	60 s
APLIED POTENTIAL LV	3 kV	50 Hz	60 s
INDUCED AC WITHSTAND	0,83 kV	200 Hz	30 s

MEASUREMENT OF SHORT CIRCUIT IMPEDANCE & LOAD LOSSES					
NOMINAL VOLTAGE (V)		MULTIPLIER		WATTMETER (W)	
11000		W.	1	1	1359,9
CURRENT (A)	33,066	V.T.	1	2	1432
U_k (V)	511	C.T.	1	3	1482,1

MEASUREMENT OF NO-LOAD LOSS AND CURRENTS					
MULTIPLIER		CURRENT (A)		WATTMETER (W)	
W.	1	2U	10,751	1	676
V.T.	1	2V	8,2836	2	387,8
C.T.	1	2W	10,48	3	195,6

CALCULATED VALUES	NO-LOAD LOSSES (P_0) Tol.=+%0 (W)	NO LOAD CURRENT (I_0) Tol.=+%30 (%)	LOAD LOSSES @ 75°C (Pk) Tol.=+%0 (W)	S.C. IMPEDANCE @ 75°C (Uk) Tol.=±%10 (%)	VOLTAGE REGULATION @ 4/4 LOAD cosØ = 1 (%)	EFFICIENCY @ 4/4 LOAD (η) cosØ = 1 (%)
GUARANTEED	1300	1,4	5120	4,65		
RESULTS	**1259**	**1,13**	**5018**	**4,66**	0,9	99,01

Oil Type	Oil Weight(kg)	Active Part Weight (kg)	Total Weight (kg)
SHELL DIALA B	315	1260	1920

This transformer meets requirements provided by IEC 60076 standards.

Customer **Approved**

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FRM-39/00

Transformer details 5000 KVA

BHEL/ PSER-KOLKATA

TENDER CHANGE NOTICE
(TCN-01 DATED 30/07/2010)

TENDER NO.:- PSER:PUR:PMX:096(VI):054 Dtd. 22/07/2010

FOR

SUPPLY OF TWO NOS. (02) 5000 KVA, 33000/11000 VOLTS STEP DOWN TRANSFORMER AT BHEL:PSER'S VIZAG SITE

FOLLOWING CLAUSES OF THE AFORESAID TENDER IS TO BE READ AS STATED BELOW:-

(1) Part – C (Technical Specification) of tender shall be as follows :--

TECHNICAL SPECIFICATION FOR 33/11KV TRANSFORMER-5MVA

Supply of 2 (Two) Nos 5000 KVA, 33000/11000 volts, step down Power transformer, 3 phase, 50 cycles, oil immersed, naturally cooled (ONAN), core type, double wound with copper conductor, having tapping range $\pm$ 5% in steps of 2.5% off-circuit tappings on HV to vary HV, 50/55°C temperature rise in oil and winding respectively, high voltage side connected in Delta whereas low voltage side connected in Star, having Vector Group Reference Dynll with neutral of the secondary winding brought out for earthing, outdoor type having porcelain bushing on HV & LV sides complete with first filling of oil as per ISS:335 and other fittings & accessories as per ISS:2026
The broad technical parameters shall be as under :

SL No		DESCRIPTION	Unit	PARTICULARS
1.		Name & type		3 ph,Oil Immersed Power transformer
2		Reference Standard		IS 2026
3		Rated Power	KVA	5000
4		Rated Voltage		
	a)	HV Winding	KV	33
	b)	LV Winding	KV	11
5		Voltage Ratio		33/11
6		Cooling		ONAN
7		Rated Power		
	a)	HV Winding	MVA	5
	b)	LV Winding	MVA	5
8		Temp. rise over ambient		

	a)	Winding (by resistance)	Deg C	55
		Top Oil(by Thermometer)	Deg C	50
9		Winding connection		
	a)	HV Winding		Delta
	b)	LV Winding		Star
	c)	Vector Group		Dyn11
10		Rated Frequency	Hz	50
11		No load loss at rated voltage & freq.	KW	5.5
12		Load loss at rated current at 75 deg C	KW	33.0
13		Impedence at rated voltage and freq.	%	7.15
14		Tolerance on losses 7 Impedence	%	As per IS:2026
15	a)	Tap Changer on HV for HV variation	%	+/-5%
	b)	Tapping Steps		2.5%
16		Regulation in % of no load voltage		
	a)	At 1.0 p.f 100% load	%	0.913
	b)	At 0.8 p.f(lg) 100% load	%	4.940
17		Efficiency in percentage at 75 degC		
	a)	At 1.0 p.f 1.00 Load	%	99.236
	b)	At 1.0 p.f 0.75 Load	%	99.362
	c)	At 1.0 p.f 0.50 Load	%	99.453
	d)	At 1.0 p.f 0.25 Load	%	99.399
18		No Load current as % of rated voltage	%	1
19		Basis insulation level withstand		
	a)	HV Winding (Lightning Impulse)	KVp	170
		(Power Frequency)	KVrms	70
	b)	LV Winding (Lightning Impulse)	KVp	75
		(Power Frequency)	KVrms	25

The transformers shall comply with IS : 2026 latest along with our specification as applicable.

Delivery : Delivery shall be within 2-4 months from date of LOI in FOR site(Vizag Thermal Power Project) basis.

Warranty : 12 months from date of supply at site.

Testing & MDCC : The transformer shall be subject to routine test free of cost as per IS: 2026 in presence of BHEL representative and the test certificate shall be submitted to BHEL for issuing MDCC (Material Despatch Clearance Certificate)

Guarantee Parameter : The bidder shall submit guaranteed parameters & GA drawings along with bid.

(2) SITE RELATED DATA : VIZAG TPP(2 X 520MW)

1.0 Site Related Data

-Longitude / Latitude : 83°07'30" E / 17°34'30" N
-Elevation above MSL : RL (+) 9 m (approximately) for main plant block
- Important Meteorological data as obtained from the nearest observatory at Visakhapatnam from 1931-1960 is as follows;
Maximum Monthly Temperature : 44.4 deg. C
Minimum Monthly Temperature : 12.8 deg. C
Maximum Relative Humidity : 84 %
Minimum Relative Humidity : 68 %
Design Relative Humidity : 80 %
Annual Mean Wind Speed : 10.8 m/sec
Maximum Rainfall : 293.3 mm in 24 hours

2..0 Seismological Parameters

The proposed project is located in Seismic Zone III, as per IS: 1893. Seismic forces would be considered as per the IS accordingly.

3.0 Wind Loading

The various design parameters, as defined in IS: 875 (Part-3), to be adopted for the project site shall be as follows:
(a) The basic wind speed "Vb" at ten mtrs above the mean ground level- 50 m/sec.
(b) Other parameters or coefficients shall be as per IS:875 (Part-3) stipulations

(3) Only supervision of Erection & Commissioning of the Transformer's shall be under the scope of Bidder.

ALL OTHER TERMS & CONDITIONS OF THE ABOVE TENDER SHALL REMAIN UNCHANGED.

Bidders are requested to acknowledge this TCN-01 in their Techno-Commercial offer.

Sr. MANAGER / PUR
BHEL:PSER:KOLKATA

Appendix-B: Conductors details

Aluminium Conductor Steel Reinforced (A.C.S.R.)

Description

- An outer layer of Aluminium conductor concentrically stranded over the central core of galvanized solid or stranded steel wires to form Aluminium steel reinforced conductor. As per BS EN 50182 or ASTM B 232 or IEC 61089.

Application

- A.C.S.R conductors are widely used for electrical power transmission over long distances, since they are ideal for long overhead lines spans. They are also used as a messenger for supporting overhead electrical cables.

Product - Code	Nominal Cross Sectional Area	Number and Nominal Diameters of Wires		Max. DC. Resistance at 20 °C	Rated Strength	Approx. Overall Diameter	Approx. Weight
		Aluminium	Steel				
	mm²	No x ø (mm)	No x ø (mm)	Ω/km	kN	mm	kg/km
a - According to BS EN 50182 - Germany							
AC0-T001-U11	16/2.5	6 x 1.80	1 x 1.80	1.8769	5.80	5.4	61.6
AC0-T001-U12	25/4	6 x 2.25	1 x 2.25	1.2012	8.95	6.75	96.3
AC0-T001-U13	35/6	6 x 2.70	1 x 2.70	0.8342	12.37	8.1	138.7
AC0-T001-U14	50/8	6 x 3.20	1 x 3.20	0.5939	16.81	9.6	194.8
AC0-T001-U15	70/12	26 x 1.85	7 x 1.44	0.4132	26.27	11.7	282.2
AC0-T001-U16	95/15	26 x 2.15	7 x 1.67	0.3060	34.93	13.6	380.6
AC0-T001-U17	120/20	26 x 2.44	7 x 1.90	0.2376	44.50	15.5	491.0
AC0-T001-U18	150/25	26 x 2.70	7 x 2.10	0.1940	53.67	17.1	600.8
AC0-T001-U19	185/30	26 x 3.00	7 x 2.33	0.1571	65.27	19.0	741.0
AC0-T001-U21	210/35	26 x 3.20	7 x 2.49	0.1381	73.36	20.3	844.1

Distribution line data

Impedance (Z)	From bus	To bus	Resistance (Ω)	Inductance (H)	Length (m)
Z01	0	1	0.0388	0.1780	160
Z1N	1	Junction N	0.0423	0.1950	178
ZN2	Junction N	2	0.0200	0.0919	83.5
ZN3	Junction N	3	0.0338	0.1540	144
ZN8	Junction N	8	0.0555	0.2569	233
Z9N	9	Junction N	0.0031	0.0143	13
ZN12	Junction N	12	0.0892	0.0384	35
ZN13	Junction N	13	0.0202	0.0935	85
Z34	3	4	0.0102	0.0556	51
Z45	4	5	0.0116	0.0539	49
Z56	5	6	0.0114	0.0520	48
Z67	6	7	0.0398	0.1840	167
Z89	8	9	0.0220	0.1018	92
Z910	9	10	0.0343	0.1580	144
Z1015	10	15	0.0593	0.2746	250
Z1516	15	16	0.0253	0.1170	106
Z1211	12	11	0.0235	0.1085	99
Z1314	13	14	0.0328	0.1518	138

CURRICULUM VITAE

Name : OMAR SAGBAN TAGHI AL-BUTTI
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QUALIFICATIONS

National Science Baccalaureate 1991, ALNEDHAMEA SECONDARY.
BSc 1996, (Bachelor in Electrical Engineering Science) UNIVERSITY OF Al MUSTANISRIY /College of Engineering/ Electrical Engineering Dept.
Professional Membership
Member of Iraqi Engineering Association, full membership since 1996.

WORK EXPERIENCE

1. November 2003 until present, I have been working as Project Engineer, (Ministry of Electricity / State Company of Baghdad Electricity Distribution).
2. October 2001- November 2003(2 years), I worked as a Design Engineer, (Ministry of Electricity /Electric power Production Projects).
3. July 2000 – October 2001(15 months), Maintenance Eng.
4. (Ministry of Electricity / State Company of Baghdad Electricity Distribution).
5. September 1999- July 2000(10 months), Services Engineer, (Ministry of Industry/ Company of Electronic Industry).
6. End of August 1998- September 1999(12 months) Services Engineer, Ministry of Health/ Abn al haitham Specialist Hospital for Ophthalmology).
7. December 1996- August 1998(2 years), Project Engineer, (Ministry of Construction/ Central Implementations Dept).

PROFESSIONAL EXPERIENCE

1. Supervising the execution of power networks (overhead high tension lines (11&33 kV). I managed a project of supplying tow large district in Baghdad with electricity. Our work includes, maintenance, execution and repairing defaulted converters
2. Design the Electrical system for building and control panels.
3. Maintenance Engineer for power distribution substations (11/0.4) K.V.
4. Maintenance Electronic equipment.
5. Maintenance Electrical for building (Generators& Cooling system).
6. Supervising the execution of electrical installation for building.
7. Good Knowledge of computer.