T. R.
VAN YUZUNCU YIL UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF ELECTRICAL-ELECTRONICS ENGINEERING

POWER FACTOR CORRECTION OF UNINTERRUPTED POWER SUPPLY SYSTEMS

M.Sc. THESIS

PREPARED BY: Sarko Othman HAMA
SUPERVISOR : Prof. Dr. Naci GENÇ

VAN-2020

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ACCEPTANCE and APPROVAL PAGE

This thesis entitled "**Power Factor Correction of Uninterrupted Power Supplies**" presented by Sarko Othman HAMA under supervision of Prof. Dr. Naci GENÇ in the department of Electrical Electronics Engineering has been accepted as a M. Sc. thesis according to Legislations of Graduate Higher Education on 24/09/2020 with unanimity of votes members of jury.

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This thesis has been approved by the committee of The Institute of Natural and Applied Science on ..……../........../…..…... with decision number ....

Signature
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Director of Institute

THESIS STATEMENT

All information presented in the thesis obtained in the frame of ethical behavior and academic rules. In addition, all kinds of information that does not belong to me have been cited appropriately in the thesis prepared by the thesis writing rules.

Sarko Othman HAMA

ABSTRACT

POWER FACTOR CORRECTION OF UNINTERRUPTIBLE POWER SUPPLY SYSTEMS

HAMA, Sarko
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An Uninterruptible power supply (UPS) is used to avoid the main power line interrupting by supplying a load. Nowadays most critical loads (Devices) are connected to an on-line UPS system to avoid all problems coming from the main power supply. Usually, the uninterruptible power supply system is considered as backup power for the electrical system, because critical load applications always rely on the UPS system to uphold continuous power, when the main power source conditions are abnormal.

Today reduction of line current harmonics or power factor correction is very necessary and in order to improve that, there are two types of power factor correction, passive PFC, and active PFC. Most commercial UPS systems used the passive power factor correction by using line LC filters to reduce the cost of the system.

The objective of this thesis is to improve the minimum Total Harmonic Distortions (THD) and PF nearly unity, by using Full-Bridge rectifier with Boost converter as an APFC with Average Current mode Controller (ACMC) using two PI Controller. In this thesis, we design and compare APFC of a different kind of UPS system (simple UPS without PFC, Off-line UPS with active PFC, and On-line UPS with active PFC) in the input and output sides for an approximately 800 VA UPS system.

A full-bridge double conversion topology was selected for its simplicity and the design topology was implemented by using the Matlab-Simulink software program to demonstrate a proof of concept for the UPS system.

As a result, we get a power factor nearly unity in the Input and output side and the total harmonic distortions are reduced to around 4%.

Keywords: Off-Line, On-Line, PFC, PI Control, THD, UPS.

ÖZET

KESİNTİSİZ GÜÇ KAYNAKLARININ GÜÇ KATSAYISININ DÜZELTMESİ

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Ana güç hattının bir kesintiye uğramasını önlemek için kesintisiz bir güç kaynağı (UPS) kullanılır. Günümüzde en kritik yükler (Cihazlar) ana güç kaynağından gelen tüm sorunlardan kaçınmak için çevrimiçi bir UPS sistemine bağlanmaktadır. Genellikle, kesintisiz güç kaynağı sistemi elektrik sistemi için yedek güç olarak kabul edilir, çünkü kritik yük uygulamalarında, ana güç kaynağı koşullarında bir anormalleşme olduğunda sürekli gücü korumak için her zaman UPS sistemine güvenilir.

Günümüzde hat akımı harmoniklerinin azaltılması veya güç faktörü düzeltmesi çok gereklidir ve bunu iyileştirmek için pasif güç faktörü düzeltmesi ve aktif güç faktörü düzeltmesi olmak üzere iki tür yöntem vardır. Çoğu ticari UPS sistemi, sistemin maliyetini düşürmek için hat LC filtreleri kullanarak pasif güç faktörü düzeltmesini kullanmıştır.

Bu tezin amacı, iki PI Kontrolcüsü tarafından denetlenen Ortalama Akım Modu Kontrolcüsü (ACMC) ve Yükselten dönüştürücülü ile beslenen Tam Köprü doğrultucusunun kullanıldığı UPS sisteminde, Toplam Harmonik Bozulmalarını (THD) minimum seviyeye çekilmesi ve güç faktörününün iyileştirmesidir. Bu tezde yaklaşık 800 VA’lık birbirinden farklı UPS sistemlerinin (PFC'siz basit UPS, aktif PFC'li Off-line UPS ve aktif PFC'li On-line UPS) aktif güç faktörünün (PFC) düzeltmesi için önerilen yöntemler tasarlanmakta ve karşılaştırılmaktadır.

Tasarım kolaylığı ve uygulanabilirliğinden dolayı tam köprü çift dönüşüm topolojisi seçildi ve benzetim çalışmaları Matlab-Simulink ortamında gerçekleştirildi.

Sonuç olarak, Giriş ve çıkış tarafındaki güç faktöründe neredeyse bir uyum elde edilir ve toplam harmonik bozulmalar yaklaşık %4'e düşmektedir.

Anahtar kelimeler: Off-Line, On-Line, PFC, PI Kontrolcü, THD, UPS.

ACKNOWLEDGMENT

I'm proud to get my master's degree at VAN YÜZÜNCÜ YIL UNIVERSITY in a friendly research environment, where I met collaborative colleagues and knowledgeable Staff and professional teachers.

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Sarko O. HAMA

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SYMBOLS AND ABBREVIATIONS

Some symbols and abbreviations used in this study are presented below, along with
Descriptions.

Symbols	Description
AC	Alternating current waveform nature of electric power
AC/DC	AC to DC conversion
D	Switch duty ratio
DC	Direct current waveform nature of electric power
DC/AC	DC to AC conversion
DC/DC	DC to DC conversion
E	Energy
FF	Form Factor
Grid	Power supplied by a large interconnected power system
$I_{in,max}$	Maximum AC input current (A)
I_L	Load Current
I_{rms}	RMS current (I)
$I_{s,rms}$	RMS value of Load Current
K_d	Derivative Gain
Ki	Integral Gain
k_{disp}	Displacement Factor
k_{dist}	Distortion Factor
K_p	Proportional Gain
M	Mass
MV	DC Voltage Transfer Function of Converter
RF	Ripple Factor
V_{dc}	DC Bus Voltage (V)

VRLA	Valve Regulated Lead-Acid
V_{rms}	RMS Voltage (V)
$V_{s,rms}$	RMS Value of Load Voltage
σ	Rectification Ratio

Abbreviations	**Description**
ACMC	Average Current mode Control
CCM	Continuous Current Mode
CICM	Continuous Inductor Current Mode
DCM	Discontinuous Current Mode
DICM	Discontinuous Inductor Current Mode
EMI	Electromagnetic interfacing
FESS	Flywheel energy storage system
HF	Harmonic Factor
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated-Gate Bipolar Transistor
KVA	Kilo Volt Amper
LC	Inductor-Capacitor
LCD Rectifier	Rectifier with Inductor, Capacitor and Diode
Mosfet	Metal Oxide Semiconductor Field Effect Transistor
PF	Power Factor
PFC	Power Factor Correction
PI	Proportional-Integral
PID	Proportional-Integral-Derivatives
PWM	Pulse Width Modulation
RC	Resistor-Capacitor
RMS	Root Mean Squared
THD	Total Harmoics Destortion
UPS	Uninterruptible Power Supply

1. INTRODUCTION

Uninterruptible Power Supply (UPS) can protect critical loads from the consequence of any shortage or interrupting of AC main power sources. Typically, electrical load or operation which need uninterruptible power supplying are like (Computers for data processes, automated manufacturing, life support devices, Communication systems, Hazard monitoring and alarm systems), (Mohan and Undeland, 1995).

Normally, the UPS system has two functions to avoid the consequence of main power problems, first to drive out spikes, frequency and minor voltage fluctuation, power factor correction, also Harmonics of the main source, and the second is to provide temporary power supplying during main power outages. To do these functions, there is a Battery in the UPS systems to continuously supply the emergency standby power to critical loads during the outages of Main power sources and to determine the accuracy of the total system.

The functionality of all UPS are the same, however is small or large. The difference in the size and the characteristics of the load determine the size and type of the UPS. Mainly the power source is supplied energy to charger-Rectifier which converts the main source power (50/60 Hz AC) to a clean Direct Current (DC) power to charge the battery set and then to provide the power to the DC to AC inverter. The inverter will convert the Direct Current power from the rectifier or the Battery to (AC) voltage as usable energy for the critical load.

In case of the main power source outages, the battery operate as the primary power source to provide energy to the inverter to ensure supplying energy for a limited time to the load, and this duration of time depends on the amount of power that saved in the battery system, or in other words it depends on size and capacity of the battery system. A UPS system must ensure energy supply is not interrupted at any time.

As usual, Most of the systems are supplied by AC main power. Today using of power converter rapidly increased. However, the power converter makes pulsating input current from grid and decreases the power factor ratio. One of biggest problems by such kind of devices is the efficiency and the power factor ratio because it contains rectifier and coils, which make more AC main line power distortions (Santhosh and Shreeshayana, 2017). The PFC (power factor correction) circuit can reduce the number of input current harmonics, Electromagnetic interfacing (EMI) and make the power factor nearly unity. We can get all these by using active power factor correction circuits. A boost type PFC circuit with an average current mode controller (ACMC) is one of the best topologies compare with another type of active PFC circuits.

Actually, Utility power isn't clean. There are nine famous problems in the utility power supplying; (Power Failure; Power Sag; Power Surge; Under-voltage; Over-voltage; Electrical Line Noise; Frequency Variation; Switching Transient and Harmonic Distortion). By law in many countries, utilities power supplier can vary widely to rising significant problems for the critical load. Emergency Generators and surge suppressors are not enough to avoid the problems of the utilities power supply outage and other disturbances because it takes time to startup and provide a power just in case of power interruption and it doesn’t help to protect the critical load from power spikes and other electrical disturbances (like power loss, under-voltage, and brownout conditions). UPS systems serve two specific purposes. They protect the load from abnormality of utility power and will supply a power in time between generator startup and utility power failure (Loeffler and Spears, 2011).

We can find different types of uninterruptible power Supply systems. The first type is standby UPS (or Off-line UPS) with transformer. This type of UPS is most common type used for small devices like computers. In normal cause, the switch chooses the filtered input power as the main source (solid line path), otherwise switches to (battery-inverter) as the backup power when the main power source fails. The second type is the line interactive Uninterruptible Power Supply system. Usually it is designed for small business like web or departmental servers. In such kind of topology, the DC-AC converter "Battery to Inverter" is constantly supplying the load which is connected to the UPS, but when the AC main power operates normally, the inverter will be operated as reverse (as charger) to charge the battery, and this features gives higher efficiency, smaller size, lower cost and higher reliability. It is also able to make a correction for line voltage condition. All these specifications make this type of UPS a predominant Uninterruptible Power Supply in size of (0.5-5 KVA power range) (Rasmussen, 2011). The third type of UPS system is On-line UPS. In this design structure the inverter works continuously whether the main supply present or not. The battery will be fully charged during the time when the utility power is there, and when main supply fails, the UPS supplies the load from backup power which stored in the battery only until the battery get discharged. When the AC main power supply resumes, the battery will be fully charged again, to be ready for next power interruption of the main power. Switching times of these power supplies are considered to be zero. For these type of UPS Usually, sealed batteries are used because of maintenance-free and the running time of power supplying from battery set is low (approximately 10 to 30 minutes). In all types and topologies of UPS, in case of a main power source outages, the battery set will be the only energy source to the inverter to ensure energy supplying to the output for a limited time, duration of time depends on the amount of power that saved in the battery system, or in another word it depends on the size and the capacity of the battery system, it means the Battery is the main parts in any kind of Uninterruptible Power Supply system (Avelar and Zacho, 2016).

All those specifications of UPS systems are dependent on the topology and design of the circuit, one of design topology is the double-conversion online Uninterruptible Power Supply system. It is most common type of UPS (above 10 kVA); and it is like the standby UPS, except that the main energy path is the inverter instead of the AC main. In this kind of design, any failure of main power doesn't cause activation of the transfer switch, because continuously main source will charge the battery set which supplies power to the output inverter. Therefore, in case of power failure, on line Uninterruptible Power Supply operates by no transfer time. Battery charger and inverter convert complete load power, and This UPS provides approximately perfect electrical output performance (Rasmussen, 2011).

To get more efficiency in any UPS system, the most important factor is the design topologies. To improve the quality of system output (power factor and to reduce the THD), the Boost converter with average current control is the most effective method to get a good result for power factor correction and stability of battery charging (Santhosh and Shreeshayana, 2017). But in case of rectifying the AC without using a step-down Transformer, we need to connect an isolated buck converter to supply the charging controller of the Batter. Another side is that the inverter also needs to be controlled to avoid a high THD and lower Power factor.

The topic of this thesis is, how we make quality of supplied power which is provided by the UPS to protect sensitive load (device) from any problem coming through an unstable AC-main power supply (Utility grid or emergency power generator), and that could be reached only with an uninterruptible power system with a high efficiency, active - PFC and low total harmonic distortions (THD). The design and topologies of the UPS is the most effective factor to reduce the losses and THD. One of the big problems of normal UPS is the efficiency of the UPS by low load and low power factor of the UPS.

Such kind of high levels of accuracy and efficiency can been only reachable with new advances in power electronics and design structures which abstract the need for internal transformers and fast switching in case of main power source interrupting. By using transformer, the losses will be three to five percentage based on amount of load. Besides, such kind of UPS needs a filter circuit by input side to minimize the input current harmonics. ("The use of high-speed processors with advanced firmware and control algorithms allows today's newest products to select the operating mode best able to supply the highest efficiency while protecting the critical load from utility grid anomalies"), (Elms, 2016).

Our target is to make a design topology of an uninterruptible power supply system with active PFC by adding controlled Boost converter with ACMC. In our project, we design three types of UPS systems and compare the Line current THD and Power factor for both sides Input and Output. We try to reduce the THD and to correct the power factor through active PFC. As active power factor correction; we design an off-line UPS system by controlling the Boost converter, using pulse width modulation, and isolated buck converter to charge the battery. Another side is that the Inverter is also being controlled to reduce the THD of the output voltage. We try to reach THD reduction of main supply to less than 5 percentages and the output THD by full load also less than 5 Percentages. In the second type, we design an on line Uninterruptible power supply system with active PFC by using a Current average modulation. The third design is a simple UPS system without any power factor correction, just to compare it with the others. Through power analysis of all three types, we make a comparison to find the effect of Power factor correction to reduce the THD and increasing the Power factor ratio.

In our design of active power factor correction, we concentrate on using a direct rectifying AC-Line wave to 311 V with a full bridge rectifier and directly supply the Dc Voltage to a Boost DC-DC converter without using a step-down Transformer.

The Boost Converter designed with a method of Average current mode controller with two PI controllers, to fix the out voltage of the circuit, correct the power factor and reducing THD. This circuit will provide 400 DC volts to the controlled isolated buck converter to step down the voltage and to provide the battery charging circuit. The battery charging controller will cut the circuit in time of complete charging of battery set. Second part of the circuit is the controlled inverter with a (PI controller) to control the output voltage with PFC and reduction of the THD for the load. The Inverter takes a DC voltage from the Battery to convert to AC sine wave to provide the power to a step-up Transformer and finally filtered the noises through an LC filters before supply the voltage to the load.

Generally, the UPS system can be grouped by the method of functionality. There are two main types (single-tracked and dual-track UPS). The single track Uninterruptible power supply provides the device all time from the rectified DC supply directly and has disadvantages because any inaccuracy in the rectification circuits leads to a total system failure. Otherwise, dual track works as a single track, but with a bypass line. In case of rectification stage fails, the load will be supplied from mains power. Hence battery set is useful only as a backup energy and doesn’t operate all the time unlike the single track.

Off-line UPS system is fairly used nowadays, mostly for low power and low-cost applications. This topology can protect loads from long-period power disturbance, such as power failure, overvoltage, and under-voltage. The switching time from the mains supply to backup power usually takes 25% to 50% of a grid cycle, which makes this topology being recommended to protect less sensitive loads. Such loads are mostly devices which works with DC voltage like the personal computer and for that reason, it is common to find Off-line UPS presenting a square or semi-sinusoidal waveform.

By the Uninterruptible power supply inverter, the output voltage should be sinusoidal with a minimum (Total Harmonic Distortion) THD, and that could be have by using a combination of (Pulse Width Modulation, PWM) schema and a second order filter at the end side of the inverter. A Pulse width modulation controller with two amplifiers should be designed, the first controls the output voltage and the other controls the output current.

The topics of our project is design and study a different type of Uninterruptible Power Supply systems with active PFC for Input and Output sides by using a controlled boost converter topology for power rate 1 KVA UPS device. In this thesis, three types of UPS systems are proposed, two of them are active PFC, a step-up-down converter with a dual controller to reduce the line current harmonics and make power factor nearly unity. Another one is just a simple UPS system without PFC just to compare with the other two UPS. With our suggest design can get a unity power factor, lower THD and adaptable step up down output voltage for universal line voltage and wide load power range.

1.1. Background

An uninterruptible power supply devices are usually considered as backup energy device, to supply emergency power for electrical systems in case of the AC main power source fails. UPS system ensures a reliable, high quality and uninterruptible power for sensitive loads that require a power supply all the time (Mohan and Undeland, 1995). UPS systems are also required to protect the critical systems against any abnormal condition from the AC main source. Generally, the UPS system is devices that convert a backup DC energy (stored in the Batteries) to an AC power when it is required. Nowadays with advantage of power electronics, high-frequency switching, and new topologies, there are different types of UPS system with different design and configuration, which take part in the main system by serving as PFC, reduction of THD and boosting (Immunity against electromagnetic interface) EMI, furthermore, isolate the load from the main source to determine all abnormality of input current wave to the load.

Normally, a UPS system includes an AC to DC rectifier, Battery-charger, Battery- set, Inverter, and LC filters in different design topologies according to the application, size, specifications, and operation requirement of the Load.

Generally, UPS is separated into three types, (Off line UPS, Line-interactive UPS, and On-line UPS). Safety and reliability of power supply for devices and systems that should work permanently are vitally important. Off line and Line interactive UPS systems have less protection for critical load, but it is widely used due to low prices. However On-line UPS systems are preferred because of safety, it makes the load is totally isolated from the main source, and guarded the load against any of transit occurrence at the utility side.

Power factor correction is necessary for any AC to DC converter to respond with the demands of the international standard. Power factor correction reduce the harmonics in the main source current, rise the efficiency and the capacity of the power system, also reduce customer utility bills. As we mentioned before, an uninterruptible power supply system needs a rectifier to rectify the AC-Voltage to DC-voltage and for that, diode rectifiers are used especially for industrial applications. Many conventional switching power suppliers run by rectifying the input AC line and filtering with a large capacitor. The capacitor draws current in short pulses. By using such kind of design, we can reduce many problems like reduction in the available power and increases the losses.

1.2. Motivation

Supplying continuously of power is the most important things for a critical load because any power interruption will cause a life like in a Hospital or alarm system, or a big loss of money and time like in a Data Center or industrial line product. The characteristics and normality of line current like poor sinusoidal sine waves are much important for non-linear load and sensitive devices. Good topology design of a UPS system with perfect power factor and minimum THD are required by supplying a critical load, and we can get it just due to an active PFC in input and output of the UPS system.

An uninterruptible power supply system has a similar concept of electrical and hybrid electric cars, and that is the future of the car industry. The subject of this thesis is a step to entry to future science and furthermore participation in the coming world industry.

1.3. Thesis Objective

Objectives to be achieved in this thesis are:

1. A typical uninterruptible power supply with input transformer could make efficiency losses from (3% to 5%) based on the load. Besides, such kind of uninterruptible power supply may also need a filter circuit in the input side to reduce the input current harmonics, and that makes even more losses. Using high speed processors with control algorithms allows today's newest products to select the operating mode able to supply very high efficiency and protects the devices from any problem coming from utility grid.
2. Make a Comparative study on different topologies and designs of uninterruptible power supply systems in front of view power factor correction and reducing the total harmonic distortions.
3. Modeling and design of an Off-line, On-line and simple uninterruptible power supply systems by using active PFC for the main source current and output-voltage to supply a critical load.
4. Controlling the converter output voltage to fix the voltage of the battery charger to avoid inrush charging current and to increase the long-life for the Batter, through design topology of full-bridge diode rectifier, step-up Boost converter, and seep-down Buck converter.

1.4. Project Specifications

The specifications for this design topology were chosen to reflect real-world UPS applications. We chose power rating of 800 W UPS, to be practice for running a small device like a PC or normally small devices. As design topology of UPS systems, we used for Off-line and On-line UPS a Full-Bridge diode rectifier, controlled Boost converter, Isolated Buck converter, Battery charger, controlled Inverter, step-up Transformer, and LC filter. The full-bridge diode rectify the AC-Voltage from main source to 311 DC voltages, and this will be up stepped to 400 Volt by boost converter with two PI controllers to fixing the output voltage and correct the power factor of the uninterruptible power supply and reduce the (THD) of the main current source. The output of the Boost converter connected directly with a controlled Isolated Buck converter to step down the voltage with a high-frequency transformer from 400 Volt to 24 volts to feed the Battery charger with a fixed voltage.

The Inverter is also controlled by two PI controllers to compare the voltage of load and a reference voltage as 311 volts (220 volts RMS). The inverter converts 24 DC volts from the Battery to 24 AC volts, and then provides the Transformer to step up the voltage to 311 volts, and then fed the load through an LC filter to determine the effect of transformer noises or voltage distortions on the load. Both sides (in and out of the uninterruptible power supply system) are controlled to makes the power factor nearly unity by the AC main power supply side and the load side, and to reduce the (THD) in the line source current.

1.5. Research Methodology

Most of the commercial UPS systems have a passive power factor correction (PFC) in line –current by using LC filters, and for the output of the system, they use an active PFC, here we design an active PFC for line-current and the output side (load) also. To do that we design a complete system's circuit for three types of UPS, including off-line, On-line with active PFC, and a simple UPS without any PFC to compare the difference between all of them.

A research methodology as defined is ("the specific procedures or techniques used to identify, select, process, and analyze information about a topic. In a research paper, the methodology section allows the reader to critically evaluate a study's overall validity and reliability"), (Anonymous, 2019).

Our methodology is associational research and we use a Matlab-Simulink software program to implement and run the design circuits for all three types. We will compare results of all types in between each other, and finally, we compare them with a similar commercial UPS that is available in market.

1.6. Scope of Thesis

Chapter two will start with UPS system topologies, where we need it, types of UPS, specifications, applications, advantages, and disadvantages of each one of them. Chapter three will explain the system components that will be used in our design topologies, and there a basic theory of the designs. Chapter four is about the design of all three UPS systems by explaining the parameters of each unit circuit separately for each system and how it works. Chapter five is about the implementation of design topologies in Matlab- Simulink software program to running and getting results to be compared in between the three types of UPS systems and compare them with a similar commercial UPS system that is available in Market.

2. LITERATURE REVIEW

Overall "no Break power" or uninterruptible power supply is the main question and the responsibility of any operator in an organization, because any power interrupting maybe cost money or sometime people life especially in Hospitals, and the aim is to supply a power contentiously to all sensitive types of equipment in the organization. All critical load needs to be supplied a power continuously and the quality of power is also important because such devices are sensitive to any non-sinusoidal input current. On another side, the PF and the input current THD impact on the power distribution system and the line utility grid too.

To avoid all power supply problems, we should take in to consideration all criteria such as type and size of the load, time and process of normalization of the emergency situation during any occurrence of main power supply fault, cost, size, maintenance, extension, replacement, communication and software, as a first step before beginning with design of an interrupted power supply system. Therefore there are a lot of topologies of UPS system, and some time is difficult to categorize the topology of UPS because it can be based on their structure, design architecture, operation, configuration, size, sinusoidal output voltage/current, reliability, efficiency, low THD, electrical isolation, power factor, and load characteristics. Actually, there is no single design that provides all of these specifications and features.

In general to simplify, first we categorize UPS systems according to their structure such as (static; rotary; and hybrid which is a combination of the other two), secondary the static types are dependent on conversion, such as single conversion, double-conversion, and multi conversion. On another side, the static UPS system is classified as off Line, online and line Interactive (serial-parallel configurations). Also for all of these types, there are single-phase and three-phase types.

For some organization such as data center it's very important to cluster the system to guaranty the power supply, there are another categorize of UPS topologies called "N topology", and structurally there are also centralized and decentralize design topologies too.

All types of UPS systems use an energy store like a battery set to supply backup power which can be supplied the load when the main power fails. From the other side emergency energy storage such as flywheel and hydrogen cell is improbable to be used in a common application in near future. Also, all types of UPS contain a "bypass" system which supplies a means of connecting the critical load to the AC main power (Green and Jackson, 2013).

Finally, we can consider the UPS system as a solution to guaranty the operating of a critical load or sensitive equipment continuously and supplying required power conditions without any interruption. Here we show each type of UPS system and how it works, the advantages and disadvantages of each one of them. By end of chapter two we could be able to know how and which type of UPS system can we choose or design for any specific load,

Here we show the most important issues about USP type and topologies.

2.1. UPS System Topology as Conversion

2.1.1. Single Conversion Systems

Generally, the AC main power supplies directly the critical load. When the main supply fails of normal limits, the UPS start to take the energy from battery set and cut the main source line to avoid back feed. The UPS stays to feed the system through the battery set until the battery run out of energy or the main source coming back to normality. There are two types of single-conversion designs, as we mention here:

- Standby uninterruptible power supply allows the critical load to operate of main power until the UPS finds a shortage; in such kind of case, it start to get the energy from the battery set. There are some UPS design structure consist of transformer or other devices to provide some criteria of a power conditions.
- Line-Interactive UPSs check the AC main power supply (Utility power) voltage, to be up or down as required and regulates it before allowing it to provide or pass through to the load, in order to protect the equipment from spike or under voltage, but other side it is like standby UPS in case of frequency abnormalities,

it uses their battery stored power by cutting the AC main source and operate the inverter to protect the load (Figure 2.1).

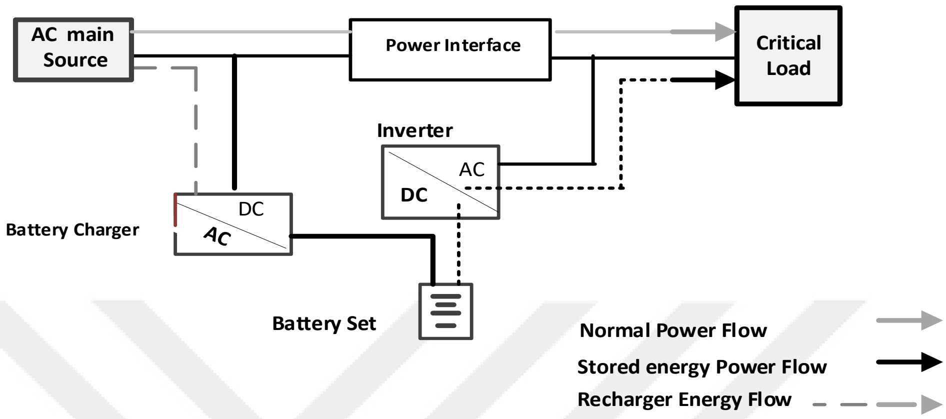

Figure 2.1. Internal Design of Line- Interactive (Single-Conversion) UPS System.

2.1.2. Double-Conversion Systems

We can understand from the name of device, it converts the power two times. First it converts AC to DC voltage through a rectifier circuit and provides the power to an output-inverter. The output-inverter then convert again the power to AC before supplies it to the critical load. Such kind of system completely isolates loads from main power; through that critical load will be supplies only with clean, reliable electricity (Figure 2.2). In normal situation of operation, this type of UPS system continuously process the power two times, but if the AC main power fails out of predefine limits, the first part of this design structure (rectifier and controller) cut off and the output-inverter starts to use the stored energy in the battery set to provide the load. When any part of the device became overload or a failure, the static bypass-switch turn on immediately to provide the loads.

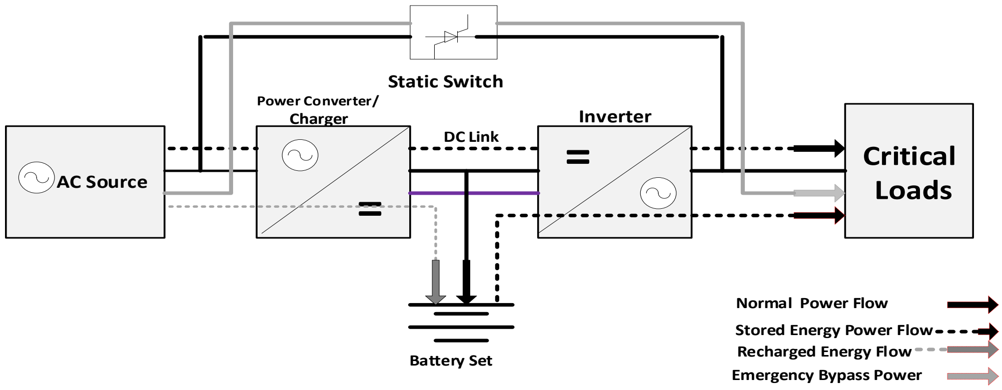

Figure 2.2. Design Structure of a Double-Conversion Uninterruptible Power Supply.

2.1.3. Multi-Mode Systems

In this system the features of both previous types of systems are combined and both reliability and efficiency of the design are improved substantially (Figure 2.3).

- In normal case, the device runs in line Interactive mode, saving energy and money.
- When main power will be out of tolerances for line Interactive mode, the system immediately switches to double Conversion mode, and isolating Load from main source.
- But when main power falls out of tolerances of the double Conversion mode, the device start to uses the battery set to keep supported loads up.

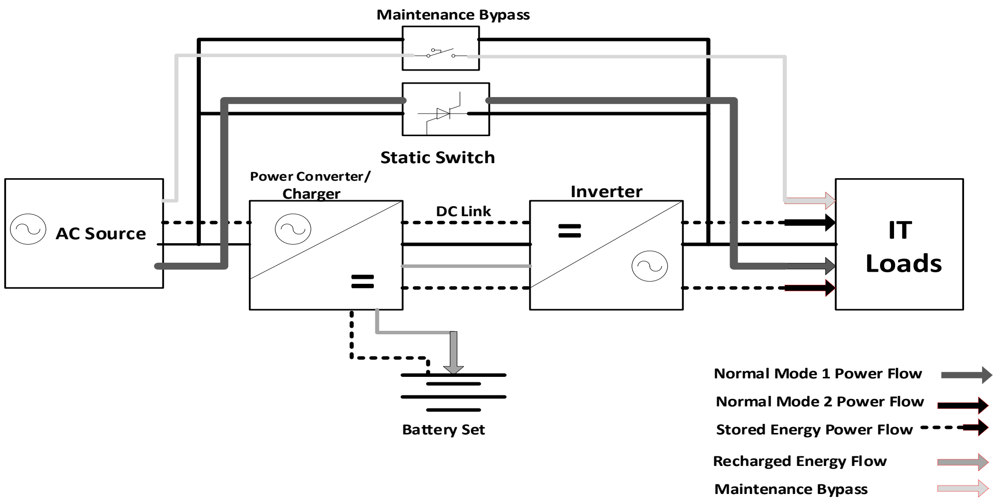

Figure 2.3. The Internal design of a Multi-Mode UPS.

2.2. Single Phase versus Three Phases

Single-phase UPSs are more economical for simpler, smaller applications with low power consumption, (<20,000 VA). While 3-phase UPSs are used for high power consumption, (like large buildings, data centers, industrial facilities).

2.3. Off Line Uninterruptible Power Supply System Topology

Off Line Uninterruptible Power Supply also called (standby or line preferred) topology mainly use for low power and low-cost applications. This topology is used to protect the load from long time power failure, under and overvoltage. The switching time to transfer from the main power supply to stored energy takes one quarter to half quarter of the grid cycle, and that makes this topology is not recommended to protect highly sensitive loads.

Generally the off-line UPS contains three main parts, AC-DC converter, battery set, and DC-AC converter; there is also a static-switch that controls the strait line between load and main supply (Figure 4.4). In this topology a passive low pass Filters are necessary to be added to the end part of the system to improve the quality of output-power, therefore there is a reason to find off-line UPS presenting a square or semi-sinusoidal waveform output voltage (Pino and Sepúlveda, 2012).

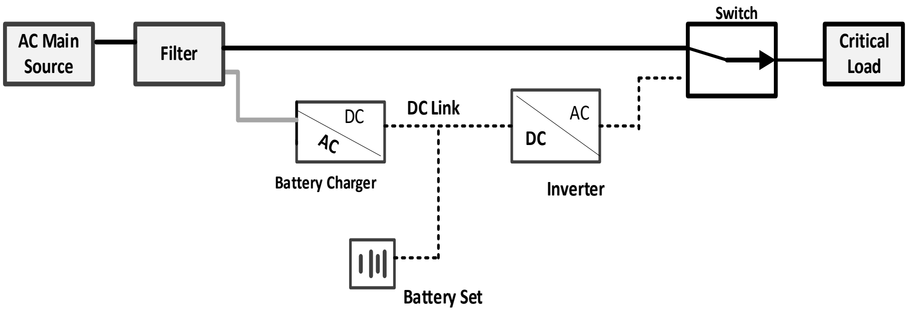

Figure 2.4. Basic Design Structure of normal Off Line Uninterruptible Power Supply system.

During normal operation, an off-line UPS feeds directly the AC main supply to the load via a bypass-line and static-switch, but the load is insecure to low voltage regulation and possibly failures, and it will be transient from the main supply to the stored power in the battery, when the main voltage across the limits. The static-switch shifts the load to the UPSs battery and inverter. The changeover-break rakes 2ms to 10ms of time; therefore an off-line UPS system is unsuitable for critical load like data center. If the mains power is not stable or the load has tight voltage-tolerance with this power quality condition or changeover break factor of this type of UPS system, the system will be forced to frequently supply interruption and change to supply the load from the stored energy in the battery set, and this frequently changeover reduce the battery long-life or insufficiently charged as result. However, applications that can tolerant this disadvantage take the benefits from firstly low cost compare with on-line UPS, and secondly its running cost, because the charger and the inverter with their inevitable inefficient are not online during normal operation. But the long switching-time and low performance with non-linear loads still as the biggest disadvantages of this type of UPS topology.

In this design topology, the power rating of the charger is about (20%) and the inverter is about (100%), it means overall the capacity of off-line UPS system topology is about (120%) of the output-power. Advantages of this topology are “high efficiency, small size, very low cost, and simplicity of design”, but the load is not isolated from any abnormality coming by the utility grid. To avoid this problem and to provide isolation, a transformer is putted between load and main power supply (Bukhari et al., 2016). In some design models, the battery-charger runs to keep the battery fully-charged and the inverter cuts off to improve the system efficiency, but the controller still operates to start the invert to supply the load when it could be needed (Green and Jackson, 2013).

As a summary we could list the key points to take into consideration before choosing an off-line UPS system:

- The output-voltage is unregulated under normal running.
- Load breaking-time pending transferring between the bypass-line and the inverter in both directions is too long for the critical load; it is about 2 to 10ms. Power protection is minimal.
- Compare with an on-line UPS, lower costs and lower running cost due to fewer components.
- The efficiency is greater than an on line UPS system because both Battery-charger and inverter are not constantly on load (Green and Jackson, 2013).

2.4. On-line UPS system topology

Because of capability of online Uninterruptible Power Supply system topology to protect the load and offering a power quality, this topology is the most used system. An on-line UPS blocks are the same as in off-line UPS, such as an AC-DC converter, a battery set, and a DC-AC converter, but all these converters are necessary to be designed at full-load rate and work as double conversion in all time,(normal running and when the main supply fails), (Figure 2.5.). The double-conversion strategy makes this topology to have lower efficiency. The battery charger keeps the battery fully charged during normal operation, and in case of the main power interruption, it will be discharged and supply the inverter to provide the load.

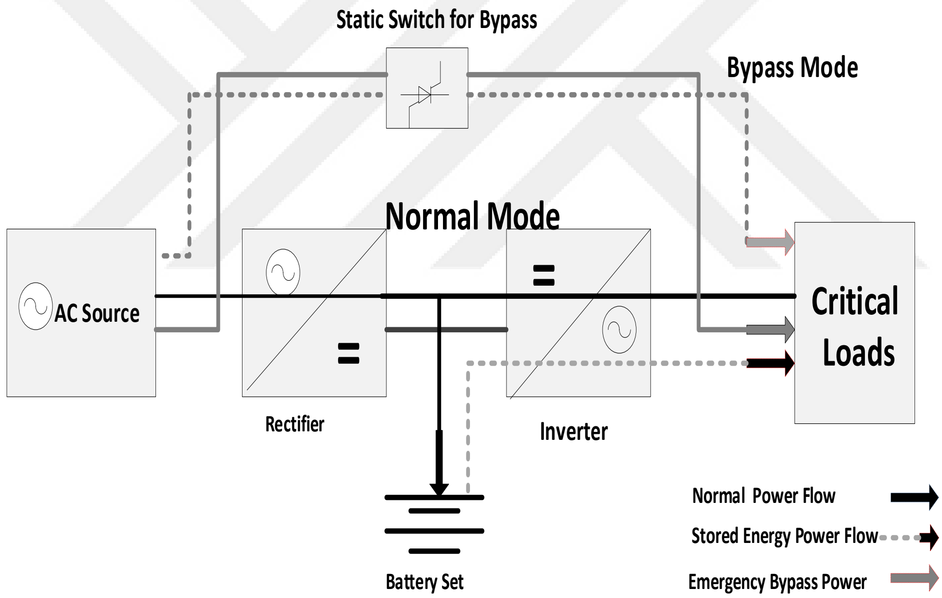

Figure 2.5. Basic Block Diagram of normal Online Uninterruptible Power Supply system.

Online Uninterruptible Power Supply system topology isolates the load from the main power supply and there is no direct load supplying from the AC mains power. Also, there is no transition-time between the normal power flow and stored energy power flow. Such kind of topology supplies (high execution, power quality and full protection) to the load, but with lower efficiency. In some type of on-line UPS, an isolated-transformer will be added in between the inverter and the load to protect the load (Hamidi, 2017).

The difference between online and off line Uninterruptible Power Supply system is; the battery-charger and the rectifier are replaced by one block. This block charges the battery and feeds the inverter at the same time, and when the main source fails, the charger will be cut off and the inverter will be fed from DC supply by the battery, it mean the battery start to discharge. The line that connects block (Rectifier-Charger) and the inverter knows as the “DC-busbar”. Online topology also contains an input current-limit feature to avoid an overload, and also contents “DC overvoltage shutdown mechanism” as a protector for all of, the battery, the inverter, and the DC filter components.

The double-conversion stage offers the highest stage of safety because the load is provided with regularly regulated power. In time, the inverter operates from battery energy; it supplies the same quality of the power as the main power supply is present.

The major disadvantages of this type of UPS are low PF and THD at the input with lower efficiency. The input-current is deformed by the rectification of the AC/DC unit; therefore a power correction circuit is added. This adding makes extra cost to this UPS topology. A PWM (Pulse Width Modulation) is applied for the rectifier to reduce the input current-harmonics and supply a stable DC-bus voltage for the output side; also a low pass-filter is added to remove the switching-frequency from the output voltage (Rashid, 2011).

These points as below should be taken into consideration when we chose an on-line UPS system topology:

- providing the load with regulated power regularly, and supply protection for the critical load.
- There is no load-break by transferring from inverter to bypass (in both interruptions).
- Power Supply failure separated from the load.
- Cost of capital is high.
- Cost of running is high because the efficiency is less than the off-line and the other types of the UPS system, because the rectifier and inverter are all-time supply the load (Green and Jackson, 2013).

2.4.1. Double-Conversion Online Uninterruptible Power Supply

Such kind of Uninterruptible Power Supply system is most common used when the load is (above 10 kVA). The block diagram of the double-conversion online Uninterruptible Power Supply as shown in Figure 2.6., it likes the standby, and just the essential power-path is the inverter instead of the main power supply.

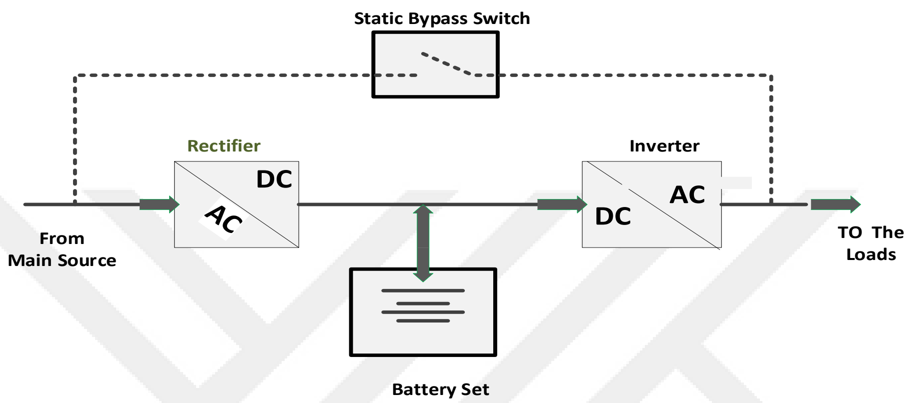

Figure 2.6. Basic Block diagram of Double-Conversion Online Uninterruptible Power Supply System.

By double-conversion online design structure, failure main supply does not affect activation of the transfer-switch, because the main power charges the battery set which supplies power to the output-inverter. Therefore, when the AC main supply source fails, there is no transit time by on-line UPS operation, because in such kind of design structure, battery and inverter provide regular the entire load power-flow. This type of UPS supplies ideal electrical output-performance. But the constant operation of the power components reduces the reliability compare with other designs.

2.4.2. Delta-conversion online Uninterruptible Power Supply

This UPS design, (Figure 2.7), is a newer (10-year-old) technology introduced to abstract the drawbacks of the double-conversion online design and “it is available in sizes ranging from 5 kVA to 1.6 MW”. It is the same as in double-conversion online design structure; in this topology the inverter supplies voltage to the load, but an additional delta-converter contributes power to the output-inverter. In case of main power fails or disturbances, the delta-conversion online UPS system behaves like the double-conversion online.

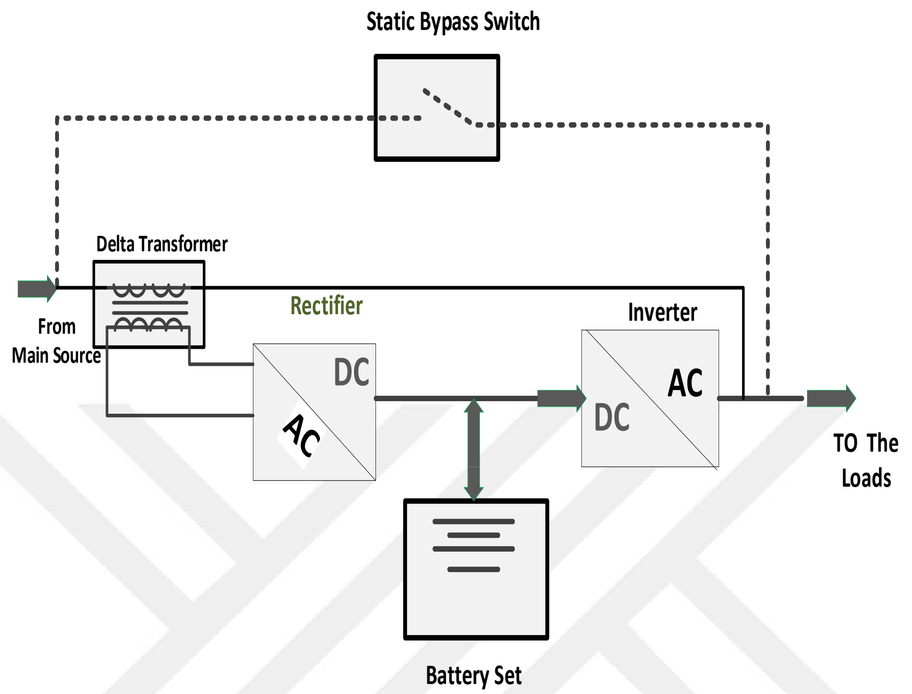

Figure 2.7. Basic Block diagram of Delta-Conversion Online Uninterruptible Power Supply System.

To understand the energy-efficiency of the delta-conversion topology is to consider the power required to deliver a package from the 4th floor to the 5th floor of a building (Figure 2.8). In this technology the energy will be saved by carrying only the difference between the starting and ending points.

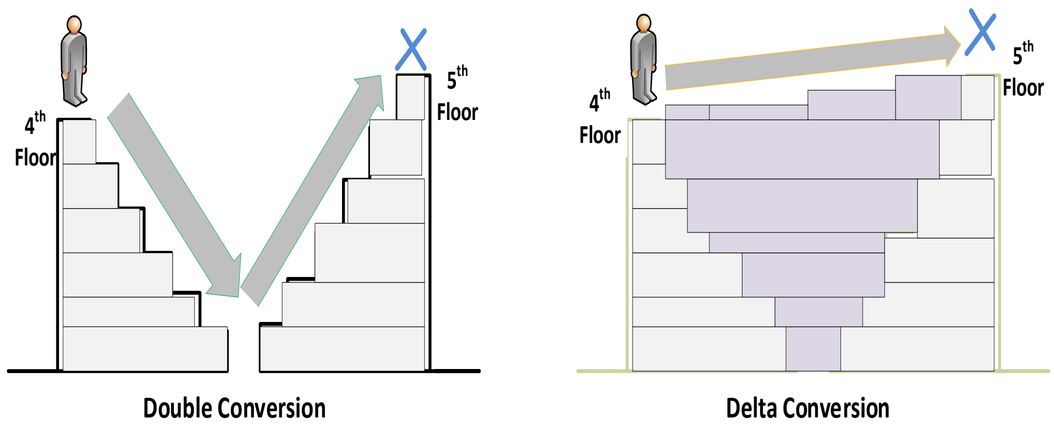

Figure 2.8. Comparing Double-Conversion Vs, Delta-Conversion.

The delta-converter in delta-conversion online system acts with dual purposes. Firstly it control the charachtristic of the input power, through that the converter draws the power in sinusoidal manner and minimize the harmonics reflection onto the AC main power source (utility); by this way it optimizes the system compatibility of utility or emergency power generator and reduces the heating and system wear in the main power distribution system. Secondly delta-converter is to control the input-current to regulate the charging of the battery system.

The advantage of this design structure is to reduce the power operating and energy losses. Other side controlling of input power makes this UPS to be compatible with all set of generator

2.5. Line Interactive Uninterruptible Power Supply System Topology

Line Interactive Uninterruptible Power Supply system Topology is a combination of the other two UPS systems, and it consists of (series inductor, bidirectional AC-DC converter, and a battery bank). The bidirectional converter supply battery-charger and also improves the PF of the load with the regulation of output-voltage. Most disadvantages of such kind of design structure are; firstly there is no isolation between main source and the load. It could add an isolation transformer to provide isolation. Secondly, the output-voltage condition isn't regular in normal mode, because the inverter is not connected in series with the load. Otherwise, the advantages of design are; its low cost, simple design, high level of performance and high efficiency, also have good harmonics suppression for the input current, (Kayaba and Akkaya, 2009). In general, there are two types of this topology, a Buck/boost transformer and a farroresnant transformer.

Normally the Line-interactive UPS system provides the load via a bypass-line from the main power supply and changes over to the inverter when the main source fails. The main power block is like the off line Uninterruptible Power Supply system, the only difference is the regulation circuit in the bypass-line and the load is transferred less often to the inverter mode. Regularly line interactive UPS system works online to improve the PF of the load. The AC-DC rectifier is connected in parallel with the load and feeds the charger. It is also used to correct the PF of the system, and reduce the output current harmonics. When the main power supply fails or when it is outside the preset tolerance, the system change over to invert mode and supply the load with power from the battery set (Rashid, 2011).

2.5.1. Buck Boost Transformer Design

One of disadvantage of Off Line UPS system is the transfer time (no power-break) to transfer the load from AC main power supply through bypass line to the inverter in case of main power fails. In Buck-Boost transformer topology, the transformer will be connected in the bypass line and helps overcome problems and also controlled the output voltage during normal mode (Figure 2.9).

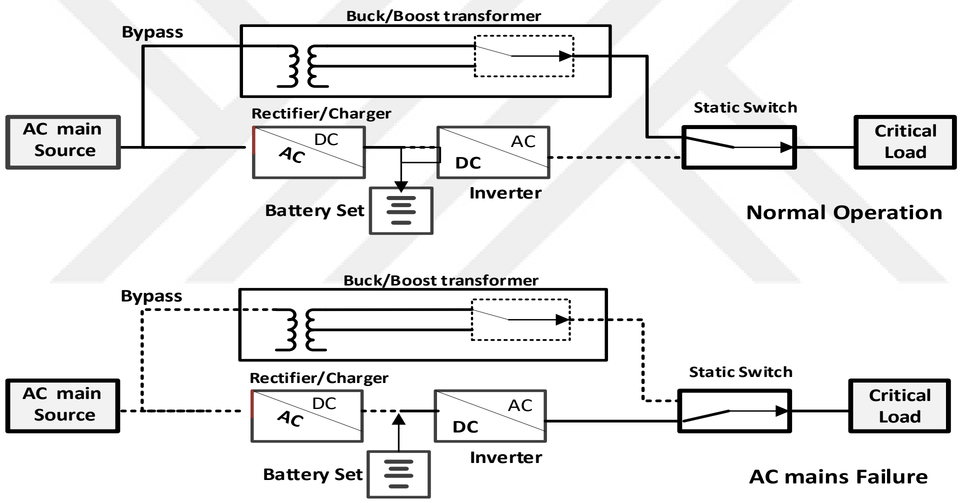

Figure 2.9. Basic Block diagram of Line-Interactive UPS System.

2.5.2. Ferroresonant Transformer Design

This kind of topology is like the Buck-boost transformer system, here the transformer regulates the power condition like noises, and the bypass voltage range spans in between – 20% and +40%. Also, it stores enough energy to supply a device like a personal computer in time of mode transferring (Figure 2.10).

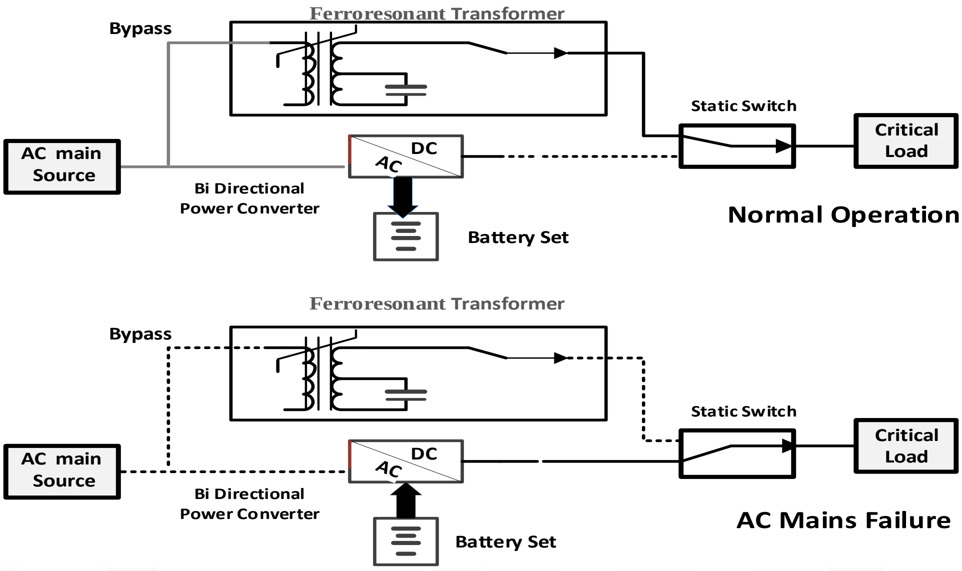

Figure 2.10. Basic Design Structure of Line Interactive UPS-Ferroresonant-Transformer.

2.5.3. Bidirectional Power Converter Design Topology

This type of design is a dual-purpose power circuit. The same circuit acts as a charging controller during normal mode, and quickly changes over to operate as an inverter in case of main power supply fails and the load will be supplied by the battery stored energy.

2.5.4. Universal UPS

There are deferent names for this UPS design topology, it called “Universal”, “Series Parallel”, or “Delta conversion”. It included; (2 bidirectional converters supply a common battery set, switch, and a series Transformer), (Figure 2.11). It is obtained from unified power-quality conditions and combines the advantage of both Online and Line Interactive UPS system. The power factor of this topology can be achieved unity, regulate the output Voltage, and simultaneously efficiency, (Rashid, 2011)

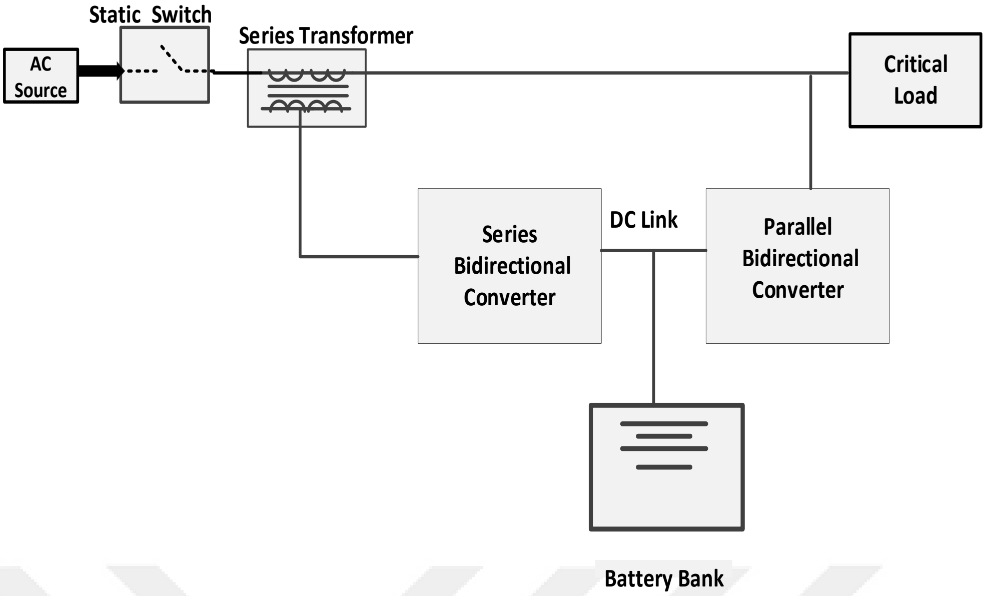

Figure 2.11. Design Structure of a universal Uninterruptible Power Supply system.

2.6. Transsformerless UPS System Design Topology

During seventies, the transformer-based and static design topologies were widely produced, however with advances in power electronics technology, the UPS industry has moved towards transformerless technology. This topology solves energy-saving, cost-saving, power quality condition, operating cost and efficiency, (Figure 2.12). In this design topology, a rectifier is followed by a controlled boost converter to boosts and fixes the output-voltage to a higher level, and this allows the inverter to strait produce an output-voltage compactable with the input voltage (Green & Jackson, 2013).

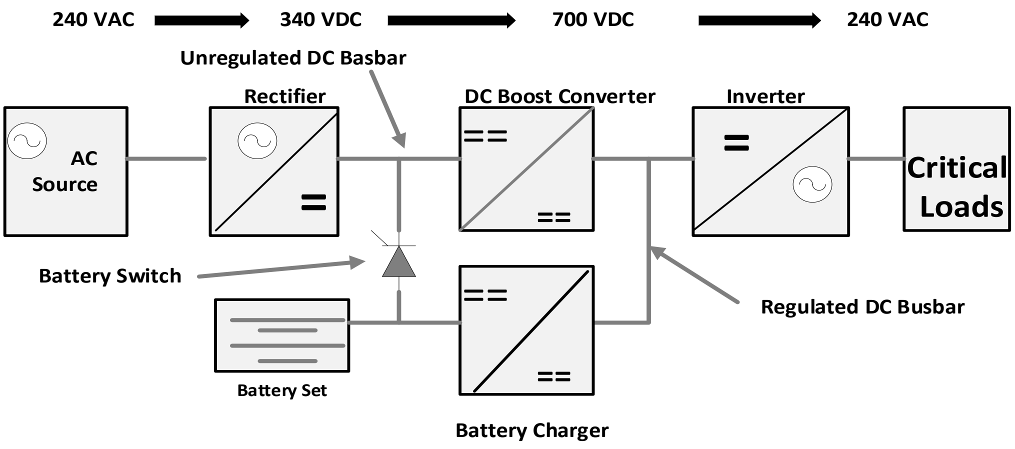

Figure 2.12. Transformerless UPS Block Diagram.

2.7. Rotary UPS

The rotary UPS system consists of a motor and generator; it is not like a static UPS system to include only static parts such as passive or active components and power converters. Generally, the rotary UPS is included (AC-Motor, DC-Machine, AC-Generator), all parts mechanically is coupled in a shaft, and finally a battery bank. When main-power is available, it drives the AC motor and rotates the common shaft and drives the DC machine. The DC-Machine then derives the AC-Generator and the generator will control the power supply to the load. When the main power fails, the battery bank drives the DC- machine, and it rotates the AC-Generator to supply the load. Generally the rotary UPS system is used supporting high power applications (Green and Jackson, 2013).

Flywheel energy-storage system (FESS) UPS, is an example of a rotary Ups system, it can be called Mechanical-Battery which it is storing electrical energy into kinetic energy (Figure 2.13). When the utility is outage, the stored energy is used in the form of electrical-power, and the amount of energy stored is proportional to the flywheel's mass and the square of its rotational speed, (Rashid, 2018).

$$E = \frac{1}{2} MV^2 \qquad \textbf{(2.1)}$$

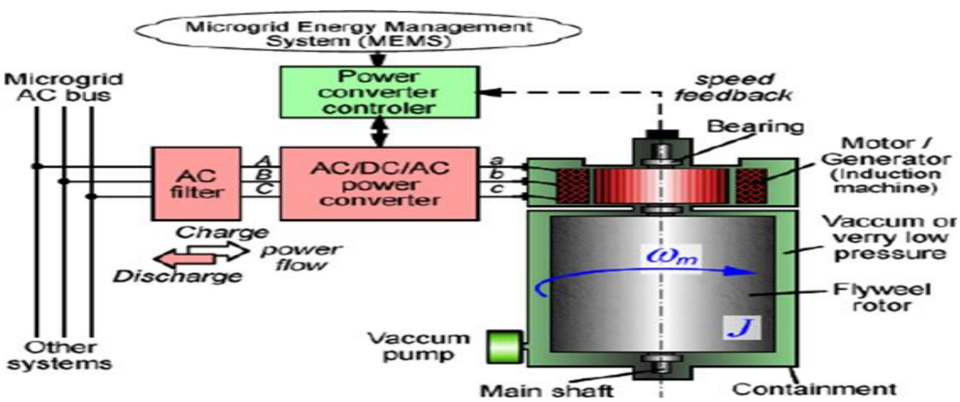

Figure 2.13. Design Structure of Flywheel Energy-Storage System (FESS).

2.8. Energy Storage Devices

To avoid power supply interruption, we need to have a device that stores energy to be ready to be used to supply continuously the power when the AC main power fails. Generally, batteries are used by most of UPS producer as an energy storage device. However, there are a couple of new technologies as alternatives to Battery such as flywheels and hydrogen fuel cells. Here we concentrate only on same types of batteries.

There are Different types of batteries to be used in UPS systems, but three types are used mostly (Nickel-cadmium, Lithium-ion, and Lead-acid) batteries, (Mohan and Undeland, 1995). Each of them provides energy and power density at a certain level, and they are different in, (cell-voltage variation throughout, different charge level, series resistance, self-discharge, and long life cycle). Normally the Battery producer will specify that their battery under certain ambient temperature and charging condition. But the UPS system ambient temperature is not exactly that battery producer specified. On the other hand, the depth discharge and frequency will be set by the power quality condition of the AC main-voltage; therefore the "long life" of the battery is lower than the "design life" of the battery (Rashid, 2018). To design a UPS system with appropriate battery, the following points should be taken in to consideration:

- How does the main power supply problems on the site?
- Dose an alternative power supply that exists like a standby generator, and the way it started to be in operation?
- Is the organization working 24 hours a day?
- How much space is available for the batteries?
- Does the load change in steps regularly?

To select the correct size of battery for a UPS system topology at least it is required to know about "Battery, Load and the back-up or autonomy time", (Green and Jackson, 2013). In the table below we present a comparison between many types of battery that are used in Uninterruptible Power Supply system topology.

Table 2.1. Comparison of different types of batteries (Ametek, 2020)

Battery Type	Typical Warranty	Life Expectancy	Hydrogen Gas Evolution	Approximate Number of Deep Discharges	Initial Cost Comparison to Lead
Lead Calcium-Flooded Cell	20 Years	20 years	Low To Moderate	100	100%
Lead Calcium-VRLA	10 Years	5 years	None	200	30-50%
Lead calcium-VRLA	20 years	12-15 Years	None	200	80-120%
Lead Antimony-Wet Cell	15-20 Years	15 Years	High	400	100%
Nickel Cadmium-Wet Cell	20-25 Years	20-25 Years	Low	1000	200-300%

2.9. Performance Evaluation

To evaluate the performance of a UPS system we should take into consideration these main four criteria as follows:

- The quality of output voltage is most important and it should be sinusoidal with low total harmonic distortion with nonlinear load and different load conditions. The control circuit should have a good response to supply the load with line condition requirements. Generally, Rotary UPS systems have better output voltage quality than static UPS systems. But by static systems, online UPS design topology provides better output voltage quality, because the output voltage is supplied by DC/AC inverter regardless of input voltage quality (Rashid, 2018).
- Transition time: it is the time to changeover from “Normal-Mode” of operation to stored energy mode. Rotary, on-line static UPS systems have a good performance regarding transition time because the output voltage is always provided by output generator or inverter and there is no transition time in between both modes of system operating. This time in the Universal and Line-interactive UPS system is dependent on the time necessary to convert the kinetic energy in the battery through the inverter to the load. Off-line UPS system has the longest transition time because it depends upon time of sensing the failure of the AC-Line and starting the inverter (Rashid, 2018).

- The input PF: Universal, Line Interactive, and Online UPS system topologies have good performance regarding the input power factor. To improve PFC and mitigate current-harmonics, an online UPS system needs an additional system for adding (Rashid, 2011).
- Efficiency: the efficiency in rotary and hybrid system depends on the size and design structure. according to "static-UPS and online UPS system" has the lowers efficiency via "Double-Conversion" compare with Line Interactive and Universal design structures, because in both design topologies the power is flows from the main source to the load when the AC main present and the system operate as normal mode (Rashid, 2018).

2.10. Power Conditioners and UPS System

Ideally, the voltage supplied by the AC main power supply should be a correct sine wave without any noise and harmonics at its nominal frequency and magnitude, and for the three-phase system, the voltage should form a balanced set. But in reality, the voltage supplied by utilities is not sinusoidal and includes harmonics; also the variation of voltage level and the frequency permanently happens. Therefore to supply a very critical load, it may be necessary to use UPS systems to protect against power outages as well as voltage and frequency irregularity (Rashid, 2011).

2.11. Decentralized or Centralized UPS System

There are two strategies to support multiple sensitive types of equipment or critical loads. Firstly, we can connect each device with a standalone UPS system as a plug and play connection; the second is to have just a large UPS system in the building integrated as hardwired into the electrical panel board. The following tables explain many factors could be considered by choosing "Decentralized-UPS" or "Centralized-UPS" (Eaton, 2019).

2.11.1. Decentralized UPS

Table 2.2. Shows the advantages and disadvantages of decentralization of UPS.

Table 2.2. Advantages and Disadvantages of decentralized UPS system, (Eaton, 2019)

“Advantages”	“Disadvantages”
Doesn’t need rewiring.	In business which supported by an emergency power generator, small off-line or line interactive UPS works not ordinary while the generator running.
Capability to growth and avoids dependency into a certain UPS.	Required monitor and maintaining multiple UPS Units.
Small UPS units don’t need to be outcast.	No opportunity to simply shut-down a single UPS with emergency Power off.
Power regulating is run at the point of use.	To extend runtime, adding maintenance bypass line or any other functionality for each one of UPS can be costly.

2.11.2. Centralized UPS

Table 2.3, shows the Advantage and disadvantage of centralized UPS System.

Table 2.3. Advantages and disadvantages of centralized UPS systems, (Eaton, 2019)

Advantages	Disadvantages
Generally, this type of UPS serves longer.	One piece of UPS means single point of failure.
One unit UPS is easier to monitor and maintain.	It will be not likely to feed all equipment from single distribution panel.
For large power consumer a three phase UPS will be more efficient and costly lower.	A centralized UPS needs more space for a large UPS, which may not be available.
A centralized UPS placed in a space where Air-Condition is more tightly controlled.	Installation and wiring costs may be higher.
By replacing a UPS batteries, its more easy to do it for a single UPS with one type of battery instead to replace different types of battery for each small UPS and it will take more time and costly.	

Both topologies can be used combine to provide redundancy for “mission-critical” applications.

2.12. Uninterruptible Power Supply Systems “N” Topologies

A UPS is used to ensure critical loads continue to function in case of the AC main power supply goes out. But here may be the UPS may fail due to many reasons. In these instances, it is advisable to have an N+1 UPS configuration or a parallel redundancy configuration (Elms, 2016). In this topology there is no problem when the main UPS module fails, because there is another UPS module as backup to be used. This will ensure the equipment connected to the system will continue to receive power. Generally, “N” represents the amount of UPSs you need, and ”+1” represents extra UPS.

2.12.1. “N” Topology UPS Systems

In this topology there is only one UPS module, it mean if this UPS fails there is no any other alternative UPS and the critical load will be directly connected with AC main power source (Figure 2.14).

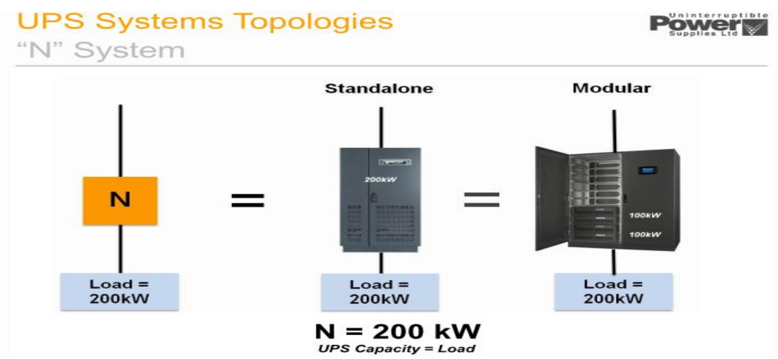

Figure 2.14. UPS System ‘N’ Topology, (Elms, 2016).

2.12.2. “N + 1” Topology System

The N stands for a UPS module while +1 stand for an additional or spare UPS module. Due to this, an N+1 UPS configuration has at least two UPS modules connected to devices. For example, if for computer serves to require six UPS modules, and N+1 configuration means the system will have a total of seven UPS devices for use. An N+1 system also called parallel redundancy, (Figure 2.15).

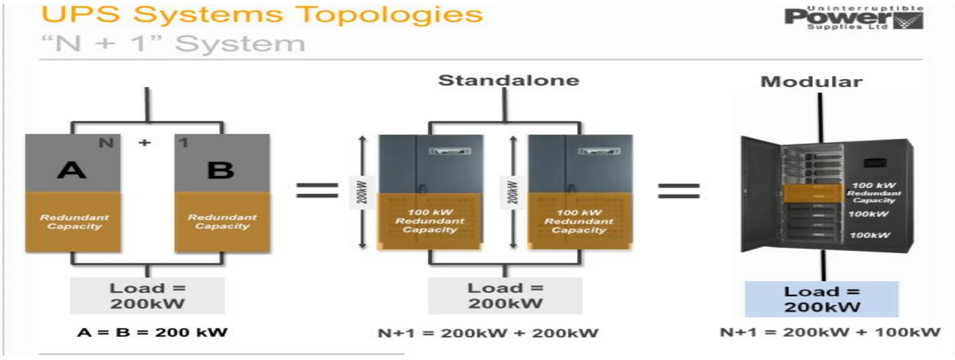

Figure 2.15. UPS System ‘N+1’ Topology, (Elms, 2016).

2.12.3. “N + N” or “2N” Topology System

2N or N+N is double the amount of UPS you need to run separately with no single points of failure (Elms, 2016), (Figure 2.16).

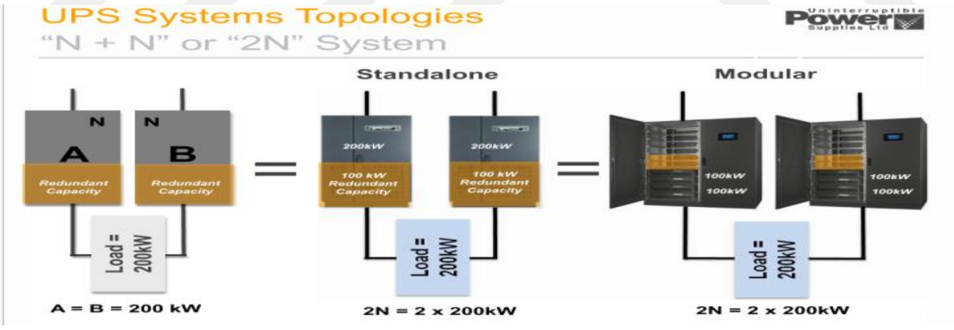

Figure 2.16. UPS System ‘N+N’ Topology, (Elms, 2016).

2.12.4. “2(N+1)” Topology System

2N+1 it is double the amount of UPS needed pulse extra pieces of equipment as well (Figure 2.17).

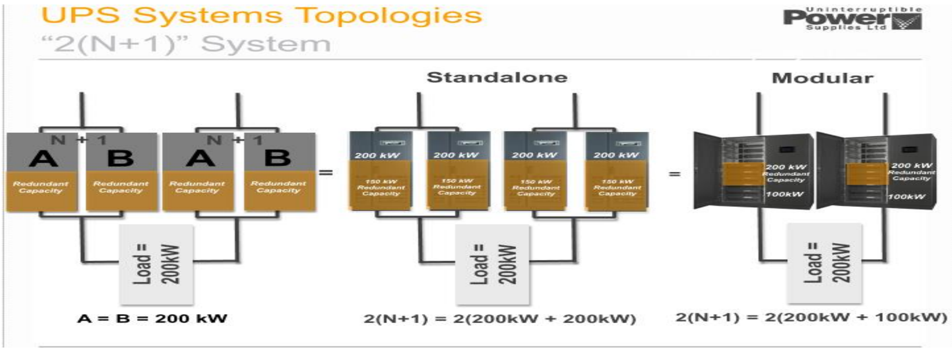

Figure 2.17. UPS System '2(N+1)' Topology, (Elms, 2016).

3. MATERIALS AND METHODS

In this chapter we try to explain the basic theory of fundamental power electronic elements which we use to design our UPS systems. As we mentioned before, we design three types of UPS systems, which will be Off-line, On-line and a very simple one to compare all of them and find the difference in between each of them.

We design the Off-line UPS with single conversion topology, which includes a rectifier, Boost converter, Isolated Buck converter, Battery charger, Controlled Inverter, step-up Transformer, an output LC filter and finally a bypass line. The on-line UPS will need similar elements; but the method will be double conversation topology. In both Off-line and On-line topologies, we add a controller for each converter, to have an active-PFC circuit using the “average current mode controlling” method. The third UPS system will be very simple without any Power factor correction to compare the results with the other two and to see the effects of adding the power factor correction circuits.

The basic theory and design structure of each part are illustrated and described in the next few sections.

3.1. Power Factor

As a concept, we can say, the power factor is equal to the cosine of the angle between the current and voltage waveform (or the ratio of the real-power to apparent-power) in an electrical AC circuit (Green and Jackson, 2013), it means the relationship between current, voltage and phase-shifted between them, or the power factor represent the measurement of the distortion caused by this shifting. In power electronics, PF represents the measure of how effective the real-power supplied from the main AC line in the system. But this concept is only true when the current and voltage concerned are sinusoidal and at the same frequency.

In general, power electronic converter has a non-leaner characteristic, which causes to distortion of the main utility power supply. Converters will cause power-quality degradation in terms of current and voltage waveform distortion and PF degradation (Rashid, 2018), because the input-PF is strongly affected by changes in the rectifier-conduction angle, falling further from unity as the rectifier phases back. Essentially the electronic power converter is a part of different power supply and a flexible control device in many systems.

The total harmonic could reduce the power-quality and the performance of power-supply system in:

- The line does not provide any real-power (in watts) to the load resulting in lower power factor and inefficient use of equipment capacity.
- Conductor-loss and iron-loss in transformers will increase and the thermal problems will be increased in the transmission system.
- In three-phase system, the current will be unbalanced and the neutral conductor will be overloaded.
- The stability of system operation will be affected by oscillation, during the propagation of harmonic within the power system.
- Automatic relay of protection devices may be affected by high peak harmonic currents. (Rashid, 2018).

The definition of power factor, it is as in Eq 3.1.:

$$\text{Power-Factor (PF)} = \frac{\text{Real}-\text{Power (Average)}}{\text{Apparent}-\text{Power}} \tag{3.1}$$

Where the apparent-power is the product of RMS values of instantaneous voltage $v_s(t)$ and instantaneous current $i_s(t)$, when the load is linear, it will draws purely sinusoidal current under sinusoidal voltage, the PF will be determined just by the phase shift between $v_s(t)$ and $i_s(t)$, (Mohanty, 2014). Hence, Eq 3,1 becomes:

$$PF = \frac{I_{s,rms}\, V_{s,rms} \cos\theta}{I_{s,rms}\, V_{s,rms}} = \cos\theta \tag{3.2}$$

where $I_{s,rms}$ and $V_{s,rms}$ are rms values of the current drawn by the load and the voltage applied to the load, respectively, and (θ) is the phase shift between instantaneous drawn current and instantaneous applied voltage. When the main power-system supplies a pure sine-waveform voltage to a linear load, during this time, the PF is equal to the cosine of θ (when θ is the phase shift angle between the instantaneous voltage and the instantaneous current).

The above equation is only for leaner loads, but the switching power devices behave as non-leaner and therefore this equation is not valid anymore. The PF calculation becomes more delicate (Figure 3.1).

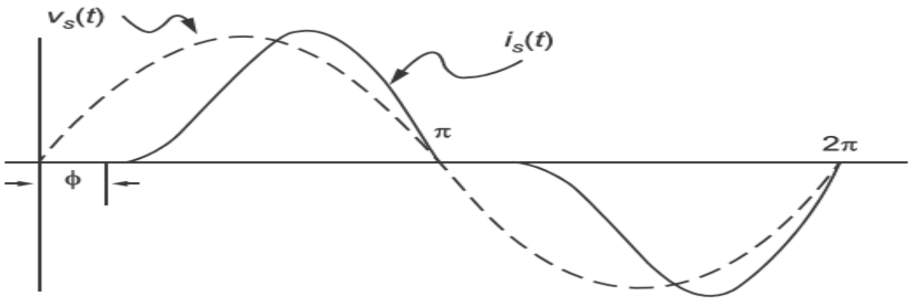

Figure 3.1. Nonlinear load draws distorted line current (Mohanty, 2014).

When we consider that power electronic circuits will be supplied an input voltage in form of a pure sine wave from the power supply voltage $v_s(t)$, now we simplify the previous equation by assuming that the voltage of power supply is a pure sine- wave and the distortions is coming only from the instantaneous current $i_s(t)$, therefore;

$$v_s(t) = V_s \sin\omega t \tag{3.3}$$

$$i_s(t) = \text{distorted (non-sinusoidal)} \tag{3.4}$$

Then, the PF could be expressed as:

$$PF = (I_{s1,rms} / I_{s,rms}) \cos\theta_1 = k_{dist} * k_{disp} \tag{3.5}$$

Where

θ_1: the phase-angle between the voltage $v_s(t)$ and the fundamental component of $i_s(t)$,

$I_{s1,rms}$: rms value of the fundamental component in line-current,

$I_{s,rms}$: total rms value of line-current,

$k_{dist} = I_{s1,rms}/I_{s,rms}$: Distortion-Factor,

$k_{disp} = \cos\theta_1$: Displacement-Factor.

It is also important to measure the percentage of current distortion which is called the current (Total harmonics Distortion, THDi) (Mohanty, 2014), and here we can define it as in Eq 3.6.

$$THDi = \sqrt{(\sum^{\infty}_{n=2} I^2_{sn,\,rms} / I^2_{s1,\,rms}} = \sqrt{(1 / (k^2_{dist} - 1))} \qquad (3.6)$$

In the reality, the input current and voltage are non-sinusoidal sine waves, it is a combination of many sine waves with different frequencies which is an integration of multiple of the fundamental frequency of the distorted wave, and the power supply system has two components, fundamental and Harmonics. All these distortions are caused by non-leaner loads, which connected with the power system.

There are different types of harmonic; we can express them in the equation as below:

$$i_n = I_n \sin 2\pi nft \qquad (3.7)$$

When

$n = 1, 3, 5$, it will be called Odd harmonic,

$n = 2, 4, 6$…it will be called Even harmonic

$n > 1$ but not integer like (1.2, 1.5, 1.7,….) it will be called Inter harmonic, and when

$n < 1$ like (0.2,0.3,0.5,….) it will be called Sub-harmonic.

The available main power must supply the power which generated by that current harmonics and of course this power will be a wasted energy (Green and Jackson, 2013).

3.2. Power Factor Correction and Total Harmonics Distortion Reduction

To minimize the Input-THD and make the current in the same angle with the voltage, we need to have a power factor correction circuit. When the PF is not unity, the current doesn't follow the voltage-waveform, and that makes losses in power and causes harmonics in the natural line, it also affects the other systems connected to the line. To solve this problem, there are two solutions for PFC and reduction of Input-THD; these are passive and active approach.

The advantages of the passive-approach are high reliability, easy to design and more power capacity. However, the operation of the passive system doesn’t achieve a high PF and highly dependent on the power system. The passive approach still a good variant in a high power application and the Active-Approach dominates the low to medium power application due to their high efficiency and performance, high density, and regulation capabilities.

3.2.1. Passive Methods of Power Factor Correction

In general, the Passive-Methods of Power Factor Correction use additional passive components in connection with the (Diode Bridge Rectifier). There are different designs of passive method of PFC; here we explain some of them.

3.2.1.1. AC-Side Inductor Rectifier

It is a very simple method, just by putting an inductor between the AC-main power and the diode rectifier, in series with the line-voltage (Figure 3.2) (Azazi et al., 2010). By this configuration, the power factor that can be obtained is 0.76 as a maximum.

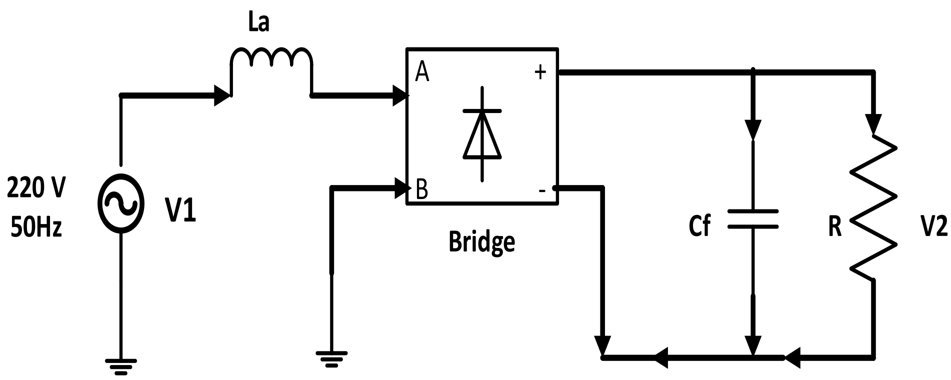

Figure 3.2. Design Structure of AC-Side Inductor Rectifier.

3.2.1.2. Rectifier with DC-Side Inductor

It can place the inductor at the DC side too (Figure 3.3) (Azazi et al., 2010). By this method, the maximum obtainable power factor is 0.90.

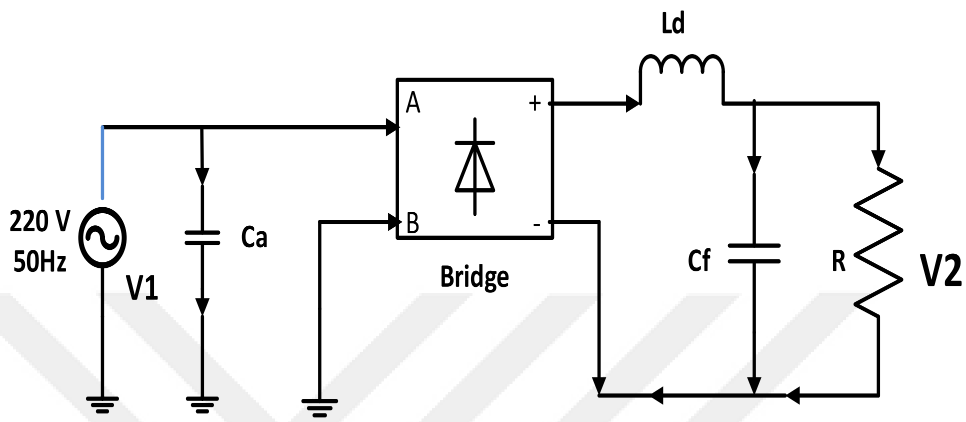

Figure 3.3. Passive PFC, Rectifier with DC-side inductor.

3.2.1.3. Series-Resonant Band-Pass Filter Rectifier

Line-Current shape could be more improved by using a combination of (low-pass input & output filters) (Figure 3.4) (Azazi et al., 2010).

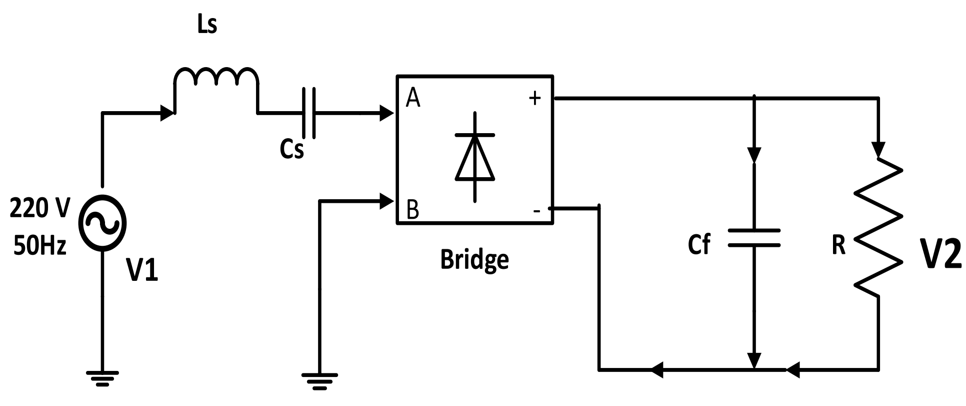

Figure 3.4. Passive PFC, Rectifier with series-resonant band-pass filters.

3.2.1.4. Parallel-Resonant Band-Stop Filter Rectifier

This Design Structure employs a Band-Stop-Filter of the Parallel-Resonant type (Figure 3.5). In this solution the filter is adjusted at 3rd harmonic to allow the lower-Value of reactive elements if it will be compared to the Series-Resonant Band-Pass filter (Azazi et al., 2010).

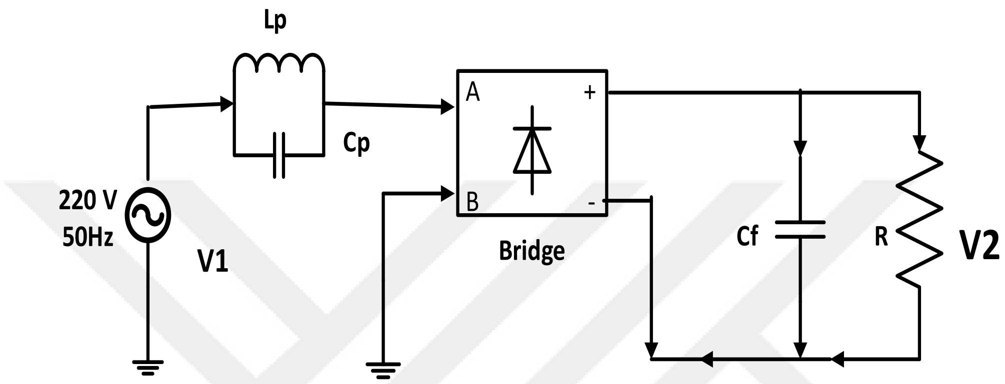

Figure 3.5. Passive PFC, Parallel-Resonant Band-Stop Filter Rectifier.

3.2.1.5. Harmonic-Trap-Filter Rectifier

This solution consists of a Series-Resonant network; conducted in parallel to the main source and tuned at specific harmonic that we want to be attenuated (Figure 3.6) (Azazi et al., 2010).

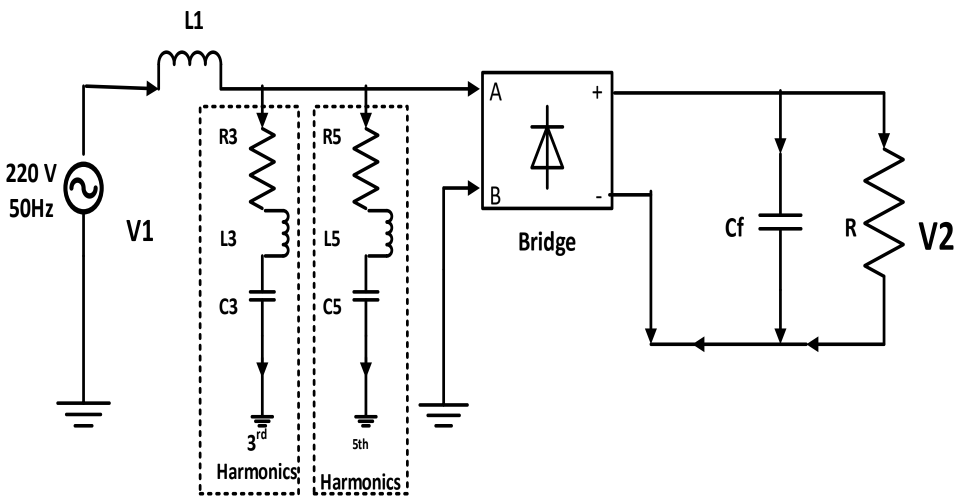

Figure 3.6. Passive PFC, Rectifier with harmonic trap filter.

3.2.1.6. Additional- LCD Rectifier

In (figure 3.7) we show a rectifier called LCD rectifier. This rectifier contents an additional inductor, capacitor, and diode (Azazi et al., 2010). The circuit changes the shape of the Input-Current, while only a limited reduction of the harmonic currents can be obtained.

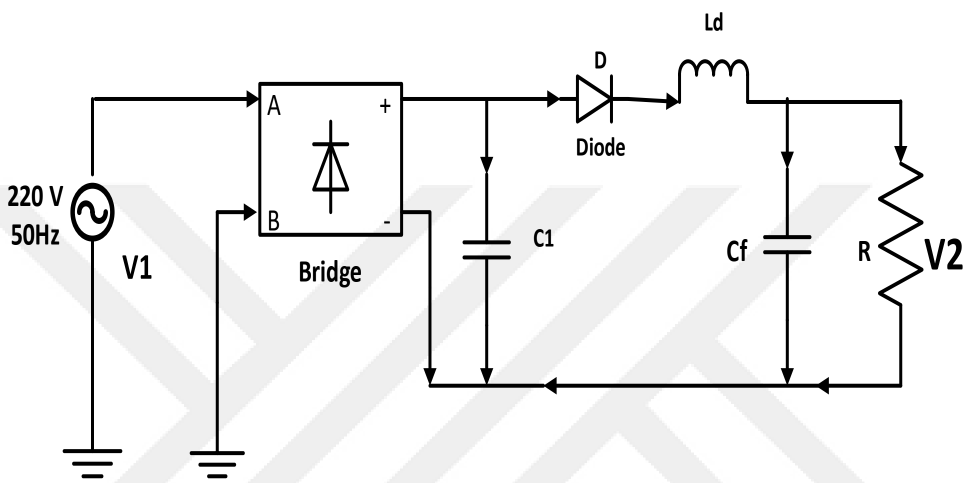

Figure 3.7. Passive PFC, Additional- LCD Rectifier.

3.2.2. Active Methods of Power Factor Correction

Through advances in power semiconductor devices by using switching devices like MOSFETs or IGBTs to shaping the line current, we could use active PFC methods.

3.2.2.1. Active PFC Low-Frequency

The circuit of this method is included a conductor, diode, capacitor and a transistor with a gate controller. Such kind of design is to control the Output-Voltage within certain limits. It is a simple, reliable, low-cost transistor required, and switching losses are very low, but the Output-Voltage regulation is slow and it needs a large inductance L_d (Azazi et al., 2010). The circuit of a Boost converter with low-frequency APFC is shown in Figure 3.8.

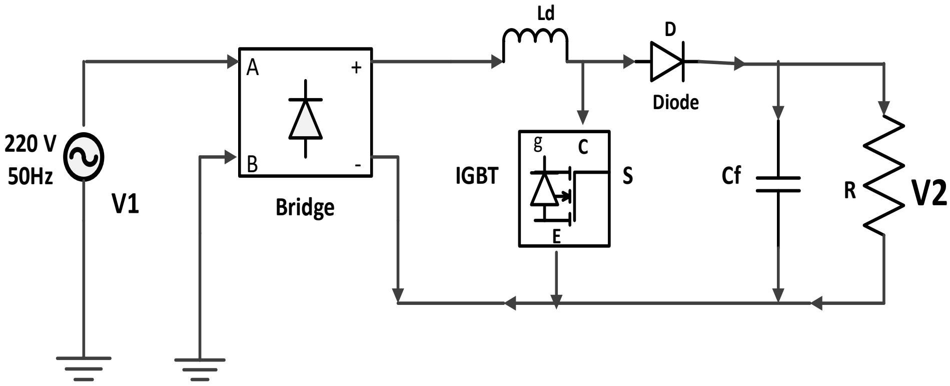

Figure 3.8. Active PFC Low- frequency circuit.

3.2.2.2. Active PFC High-Frequency

With power factor correction can be used a DC-DC converter with a switching frequency higher than the fundamental frequency of AC main line. Generally, any DC-DC converter with a suitable Control-Design to shape its input line current can be used for this purpose. The converters can operate in both CICM (Continuous Inductor Current Mode), and DICM (Discontinuous Inductor Current Mode) (Azazi et al., 2010).

There are different types of DC/DC converter to be used for high- frequency active topology of power factor correction (PFC). Here we explain shortly four types of them.

3.2.2.2.1. Buck-Converter

The Buck converter (Figure 3.9), step the input voltage down to lower voltage. It means the output voltage will be lower than the input voltage.

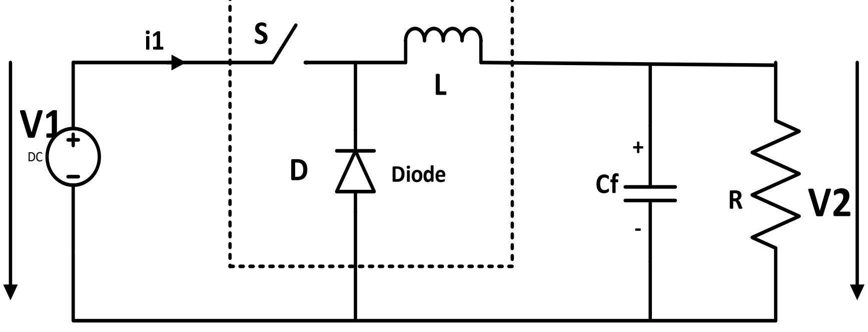

Figure 3.9. Buck-Converter as High-frequency active circuits of PFC.

3.2.2.2.2. Boost-Converter

The boost converter (Figure 3.10) is the most common design topology used for PFC, and it step the input voltage up. It means the output voltage will be higher than the input voltage. This type of converter can operate in two modes, CCM (Continuous Conduction Mode), and DCM (Discontinuous Conduction Mode) (Azazi et al., 2010).

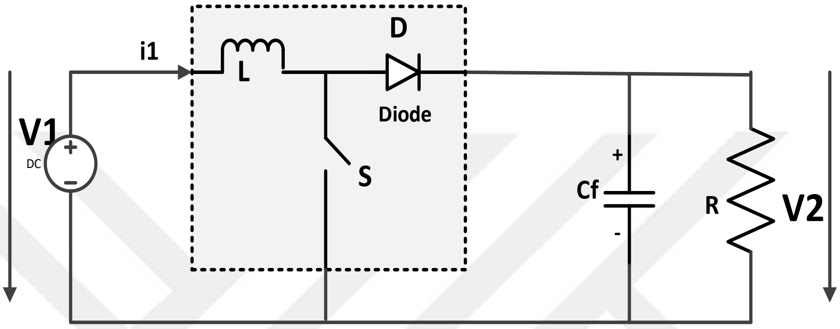

Figure 3.10, Block diagram of Boost converter for PFC.

3.2.2.2.3. Buck-Boost-Converter

This design topology of a converter (Figure 3.11) can operate in both operations (step-down or up) the output voltage; it means that the output voltage can be lower or higher than the input voltage.

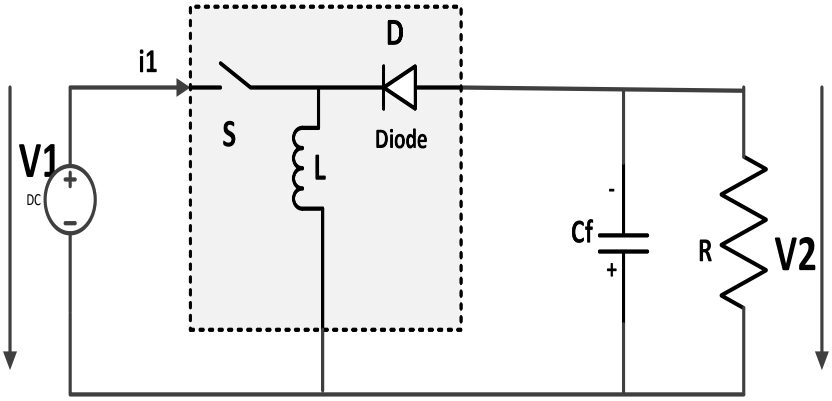

Figure 3.11. Block diagram of Buck-Boost converter for PFC.

3.2.2.2.4. PWM rectifier

The PWM (Pulse width Modulation) rectifier (Figure 3.12) is another PFC topology and it can step-up or step-down the output voltages. It needs (2 or 4 by employing Half- or Full-bridge configuration) Power-Switches to achieve the unity PF.

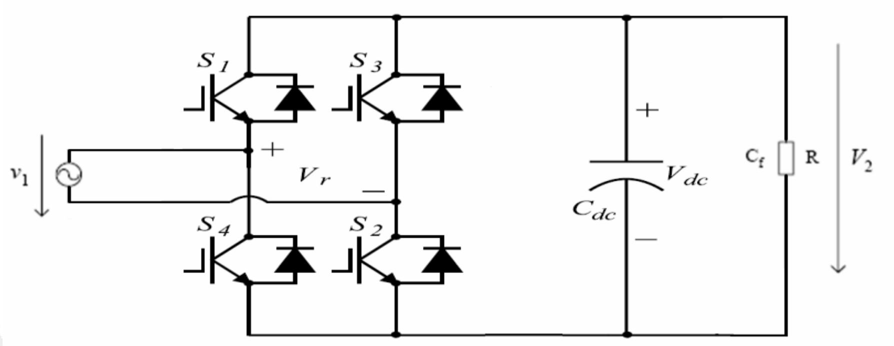

Figure 3.12. P Block diagram of PWM rectifier for PFC (Azazi et al., 2010).

3.3. Full-Bridge Diode rectifier

There are different types of a diode rectifier, half-wave, full-wave, single-phase, three-phase, controlled rectifier, and more. Here we concentrate on a single-phase full-bridge diode rectifier because we need it latter in our design.

There are also two types of single-phase full-wave rectifiers; one is with center-tapped Transformer as showing in Figure 3.13.

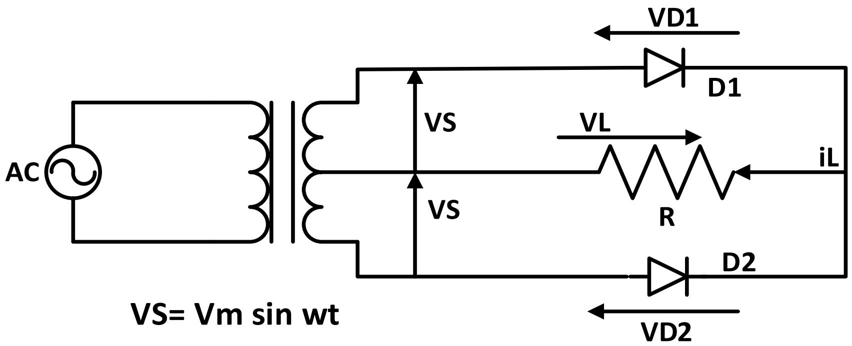

Figure 3.13. Full-Wave Rectifier with Center-Tapped-Transformer.

In this design, each half of the transformer with associated diode acts as a half-wave rectifier. Since no DC currents are flowing through the transformer, there is no

DC Saturation-Problem of the transformer core (Rashid, 2018). The average Output-Voltage is:

$$V_{dc} = \frac{2}{T}\int_0^{T/2} Vm \sin wt dt = \frac{2Vm}{\pi} \quad (3.8)$$

The second type of Full-wave Diode (or Bridge) rectifier uses four diodes instead of a Center-Tapped-Transformer. During the positive Half-Cycle of the input-voltage, the current flows to the load through (D1 and D2), during the negative cycle, diodes (D3 and D4) conduct as shown in Figure 3.14. The peak of diode voltage is only V_m.

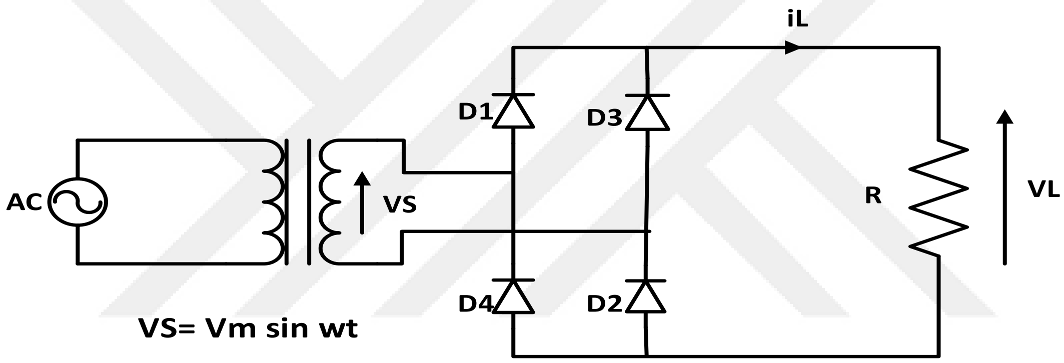

Figure 3.14. Single-phase Full-Bridge rectifier.

3.4. Controlled Boost Converter

The Boost converter as showing in Figure 3.15, is a step-up converter, it consists of an (inductor, diode, transistor, and a capacitor). The operating of this converter is while the switch (MOSFET or IGBT) is on (charging mode), the inductor is storing energy, and once the switch is off (Discharging Mode) the stored energy in the inductor supply the load (Block, 2015).

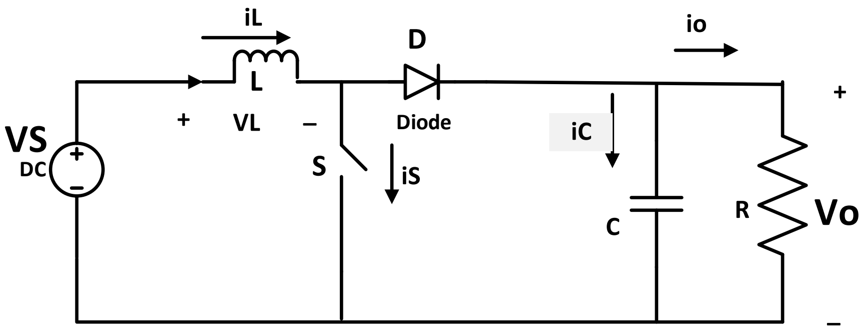

Figure 3.15. Circuit diagram of Boost converter.

This circuit maximizes input power factor by controlling input current and makes it sinusoidal with keeping it in phase with input-voltage. This is achieved by pulse-width modulating (PWM) technique; also with this technique the circuit reduces the input line THDs (Green and Jackson, 2013).

3.5. PID Controller

The PWM (Pulse Width Modulation) controller regulates the Output-Voltage by changing the Duty-Cycle of the transistor switch. The Duty-Cycle is the ratio of the period where the switch is kept on to the cycle period. Pulse Width Modulation is used in a wide variety of systems, and it is a technique for controlling Analog-Circuits with a processor Digital-Output. In this topology, the transistor switch determines how the load will be supplied and controlled. This algorithm is used for each conversion process, like inverter, rectifier, buck, and boost converter.

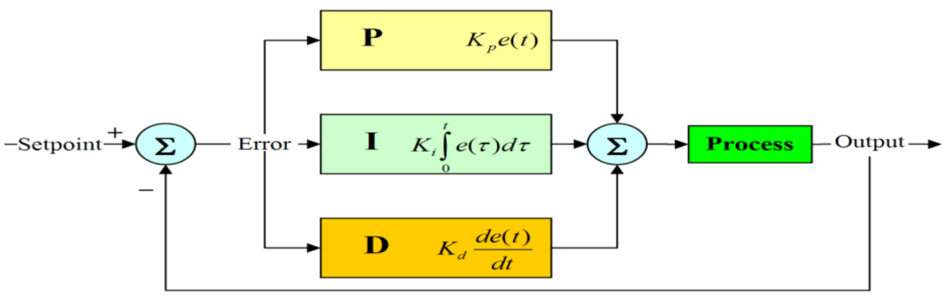

Figure 3.16. Block diagram of a PID controller, (Singla and Singh, 2014).

In our project we will use PI controller in controlled boost circuit. In general, the PI controller works to minimize the error difference between the desired Reference-Value and the actual Measured-Value using two control variables; the proportional gain term and the integral gain term (Lee et al., 2016).

3.6. Isolated Buck Converter

As we mentioned before, a Buck-Converter is a step-down DC to DC converter. The circuit diagram (Figure 3.17) consists of a DC-Voltage Source Vs, Transistor S (as Controlled-Switch), diode D, Inductor L (as filter), Capacitor C (also as filter), and a Resistance load R. in this topology the inductor current is always positive, and this converter is called as CCM (continuous conduction mode), because the Inductor-Current is never be zero for any time.

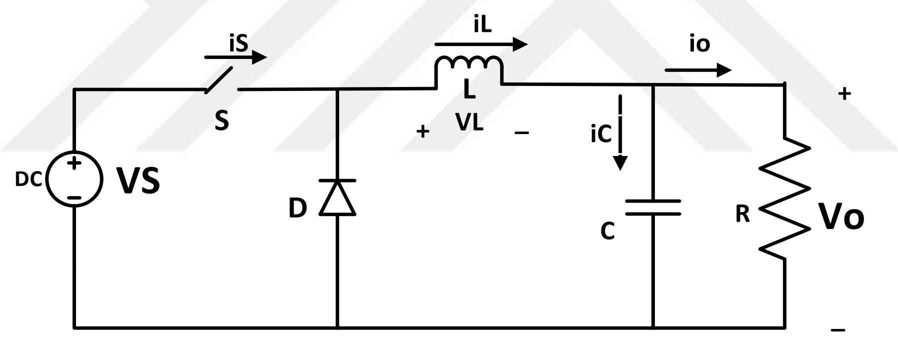

Figure 3.17. Circuit diagram of Buck (step-down) converter.

We can derive the relationship among the Input-Output voltage, and the Switch-Duty ratio (D) from the Inductor-Voltage V_L waveform. According to Faraday's law, the inductor volt-second product for steady-state operation is zero. For the buck converter,

$$(V_s-V_o)DT = - V_o(1-D)T \tag{3. 9}$$

Hence, the ratio of output to input voltage can be called as voltage transfer function.

$M_v = \frac{Vo}{Vs} = D$ (3.10)

In this topology, the Output-Voltage is always smaller than the Input-Voltage (Rashid, 2018). For the Buck-Converter, the value of the filter inductance that determines the boundary between CCM and DCM is given by:

$L_b = \frac{(1-D)R}{2f}$

(3.11)

And

$C_{min} = \frac{(1-D)Vo}{8VrLf^2}$

(3.12)

For safety and reliability, in many DC-Power supply a galvanic isolation between the Input and the DC output is required, and that could be by using a high frequency transformer to provide high efficiency and additional adjusting for the output voltage levels. There are different kind of designs like half-bridge, full-bridge, forward, and Push-pull converter (Rashid, 2018). Here we concentrate on Full-Bridge Isolated buck converter as shown in Figure 3.18.

By PWM DC-DC Full-bridge converter the input capacitor as in half-bridge converter has been replaced by two-transistor (Controlled switches), as shown in Figure 3.18, and both of these transistors are operated in pair. When transistor (S1 & S4) is on, Vs voltage is applied to the primary of the transformer, and (D1) conducts, when (S2 & S3) on, there is Vs voltage across the Primary-Transformer and (D2) is on. With all transistor switches off, both diodes conduct.

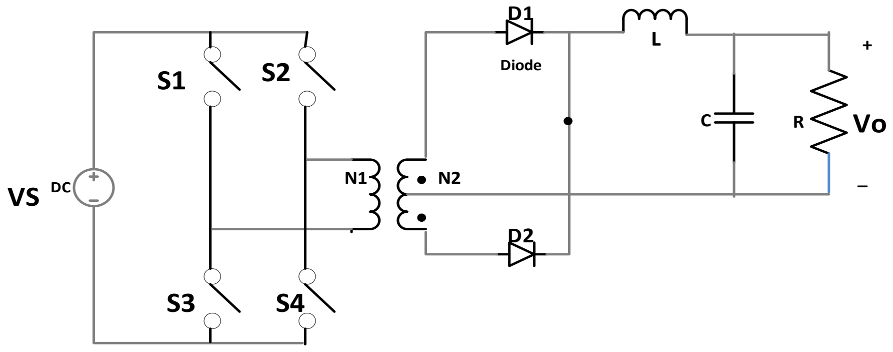

Figure 3.18. Isolated buck converter (Full-bridge DC-DC).

The DC-Voltage transfer function of this converter is,

$$MV = \frac{Vo}{Vs} = \frac{2D}{\pi} \tag{3.13}$$

The full-bridge topology with different control algorithms (square-wave and PWM single-phase inverters) is very popular in DC-AC conversion (Rashid, 2018).

3.7. Battery

The most important part of an uninterruptible power supply system is the batteries to store energy as a back-up supply source. To choose a suitable battery, the designer should know which kind of batteries will be needed to be used in the system, and how the system protects the batteries from under-over charging and over-discharging. Also, heat sinking and Control of UPS ambient temperature is much important to protect the batteries from overheating at higher than normal temperatures (Green and Jackson, 2013).

There are many factors and characteristics of the system that should be taken into consideration to design and used a correct battery or battery set.

3.7.1. Battery Types for UPS System

Each type of battery has a different specification, here we explain some of batteries that are widely used in UPS systems and how we calculate the size and numbers of the batteries needed for each system.

3.7.1.1. Lead Acid Battery

It is a re-chargeable battery and it can provide a large power for a relatively low cost. This type of battery is used for applications in which surge power with low depth discharging is required (like UPS system). The disadvantages of this type are low energy density and short life cycle (Hamidi, 2017). There are two main types of Lead-Acid battery used widely in Uninterruptible Power Supply systems, open-Vented and Sealed or valve regulated Lead-Acid (VRLA).

3.7.1.2. Lithium-Ion battery

This type of battery is used for many applications because it has good performance and specification. High power density, long life cycle, high efficiency, low self-discharging, and good performance are the advantages of lithium-Ion battery and make it widely used battery in different systems (Hamidi, 2017).

3.7.1.3. Sodium Sulfur (NaS) Battery

It is also re-chargeable battery and mostly developed for a large scale power system that operates at extreme ambient temperatures (+300 to -350 C^{o}). The advantages of this type of battery are high efficiency up to 90%, low cost, high energy strange, good thermal behavior, and long life cycle (Hamidi, 2017).

3.7.2. Design Life

Each type of battery has a Design-Life and it is determined by the producer based upon a certain assumption about the environment in which the battery will be operating, store, and how the battery will be used. In UPS system, the depth of discharge, frequency, and the ambient temperature are not exactly like that specified by the battery manufacturer because it depends on the quality of the AC main line from utilities, and that makes the useful working of the battery is less than the design life of the battery (Green and Jackson, 2013).

3.7.3. AC Ripple

To charge any battery, we need a pure DC-Voltage. An AC-Voltage upon this DC- Charging-Voltage is called AC-Ripple, and it will adversely affect the Long-Life cycle and useful working of the battery (Green and Jackson, 2013).

3.7.4. Choosing the Correct Battery Size

The UPS battery must support the load as a back-up time to gives the user enough time to start an alternative source like a generator or an ordinary shut-down of critical load in case of a full or partial loss of main power supply line from utilities (C&D Tech. 2013).

To calculate, there are two necessary information when we select battery with correct size, firstly the Battery-Load and secondly the necessary back-up time. Battery load can be calculated by adding the actual UPS load and the power losses in the UPS output section (Inverter, Transformer, LC filters). And for Battery-Sizing, there are different types and sizes of batteries produced by manufacturers. The battery suppliers provide information to be useful by design and size calculation of the UPS battery. Generally, they give the size of the battery in Kilowatt per cell, Kilowatt per bank, or ampere per cell; therefore, it is important to calculate the total kilowatt required to operate the UPS at a given load.

$$\text{KW/cell} = \frac{\text{KVA x PF}}{\text{EFF x Number Of Cells}} + \text{AL} \qquad (3.14)$$

Where:

KVA = KVA of the load

PF = Power factor of load

EFF = Efficiency of the UPS at the given load

No. Cells = Number of cells required.

AL = any additional loads on the battery expressed in kilowatts.

To calculate the size of battery set that we need and the average current of the Battery through looking to the chart (Figure 3.19) of battery discharge rate and specifications to find the available output for specified periods of time and using the equation as below:

$$\text{DC Amp} = \frac{\text{KVA x PF x 1000}}{\text{EFF x DCV}} + \text{AL} \qquad (3.15)$$

KVA = KVA of the load

PF = Power factor of the load

EFF = Efficiency of the UPS at the given load

DCV = Average Discharge Voltage - For a 130 VDC system, this is 109V

A**L** = Additional loads expressed in amperes**.**

Usually, the UPS battery load is provided in terms of kilowatts, to calculate the number of cells in parallel and/or series we should know about the inverter nominal DC-bus voltage, minimum operating voltage, and the required operating of the UPS system as back-up time. To calculate runtime of UPS battery, we should take into consideration the amount of load required to be run in back-up time, charger type, DC-bus voltage, UPS efficiency, and the battery type.

AVERAGE CELL PERFORMANCE DATA* (Discharge Rates in KW)**

Specific Gravity 1.215

TYPE	3 HR	2 HR	1.5 HR	1 HR	45 MIN	30 MIN	25 MIN	20 MIN	19 MIN	18 MIN	17 MIN	16 MIN	15 MIN	14 MIN	13 MIN	12 MIN	11 MIN	10 MIN	5 MIN
	TO 1.75 END VOLTS PER CELL																		
CX-5	0.041	0.052	0.062	0.086	0.100	0.129	0.144	0.159	0.163	0.167	0.171	0.175	0.180	0.185	0.191	0.197	0.204	0.212	0.244
CX-7	0.061	0.078	0.094	0.129	0.151	0.194	0.216	0.239	0.245	0.250	0.256	0.262	0.270	0.278	0.286	0.296	0.307	0.318	0.367
CX-9	0.082	0.105	0.125	0.172	0.201	0.259	0.288	0.319	0.326	0.334	0.342	0.350	0.360	0.370	0.382	0.395	0.409	0.424	0.489
CX-11	0.102	0.131	0.157	0.215	0.252	0.324	0.360	0.399	0.408	0.417	0.427	0.438	0.450	0.463	0.478	0.494	0.512	0.530	0.612
CX-13	0.123	0.157	0.188	0.258	0.302	0.389	0.432	0.479	0.490	0.501	0.513	0.525	0.540	0.555	0.573	0.593	0.614	0.636	0.734
CX-15	0.143	0.184	0.220	0.302	0.353	0.453	0.503	0.559	0.571	0.584	0.598	0.613	0.630	0.648	0.669	0.692	0.717	0.742	0.857

Figure 3.19. Discharge rate in KW per cell as back-up time of a battery, (Ametek, 2020).

3.7.5. Battery Charger Sizing

When battery discharging, it is important to recharge again the battery quickly to be ready for the next power interruption. Generally, the battery charger can recharge the battery to 85% of its capacity in (8-10) times the Discharge-Time. Here we use a formula to calculate the size of a battery charger with including also the DC power to be supplied to the inverter at the same time with the charging process (Ametek, 2020).

$$\text{Charger Size in Amps} = \frac{\text{IB x TD x K}}{\text{TR}} + I_I + I_A$$

(3.16)

Where:

I_B = Battery Current Required = $\frac{\text{Inverter VA x Power Factor}}{\text{DC to AC Efficiency/DCV}}$

I_I = Inverter Current Required= $\frac{\text{Inverter VA x Power Factor}}{\text{DC to AC Efficiency/Float Voltage}}$

I_A = any additional DC-Loads in amperes

T_D = Battery-Discharge (Run) Time in hours

T_R = Battery-Recharge Time in hours

K= Safety factor (typically 1.5)

3.8. Controlled Inverter and Principle of Operation for Single-Phase Bridge Inverter

An inverter is used to produce an AC-Output-Waveform from a DC-Power supply. These types of the converters are used in many applications; the UPS system is one of them. To produce a sinusoidal AC output, frequency, phase of the waveform, and magnitude should be controllable (Rashid, 2011).

There are different types of inverter, at the beginning it is sorted as single-phase and three phases. Here we concentrate on the single-phase Inverter topology (Liu, 2016). The variation based on the number of switches (Half-bridge and Full-bridge inverter), Input-Output sources (Current-Source and Voltage-Source Inverter), and comparing the Input-Output peak voltage (Boost, Buck, Buck-Boost Inverter) or step-up and step-down inverter (Suman, 2014).

The Output-Voltage-Waveform of the Ideal-Inverter should be sinusoidal, but in practice, the waveforms are Non-Sinusoidal and contain certain harmonics. For low and medium power application, Square-Wave may be acceptable but for High-Power-Applications, low distortions Sinusoidal are preferred. With advanced power electronics, the harmonic contents of the Output-Voltage can be reduced by switching techniques (Rashid, 2011).

A Single-Phase Bridge Inverter is consisted of four switches (Transistors) as showing in (Figure 3.20). When Transistor Q1 and Q2 turn on, the Input-Voltage (+Vs) appears across the load. If Transistor (Q3 and Q4) turn on at that time, the output voltage across the load is reversed and it is (–Vs) (Figure 3.21) (Rashid, 2011).

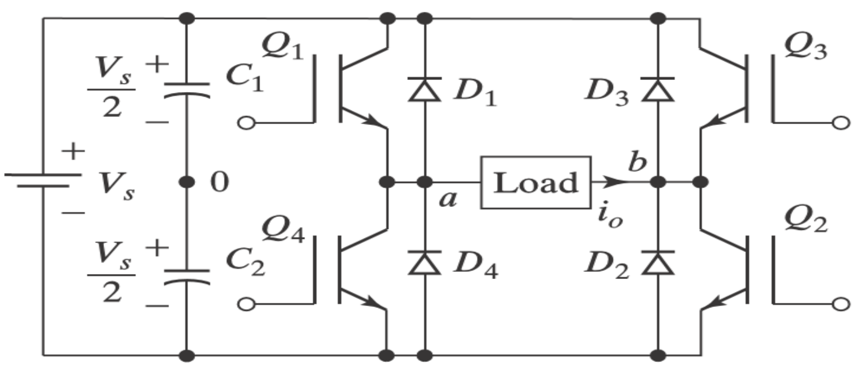

Figure 3.20. Block Diagram of Single-Phase Full-Bridge inverter (Rashid, 2014).

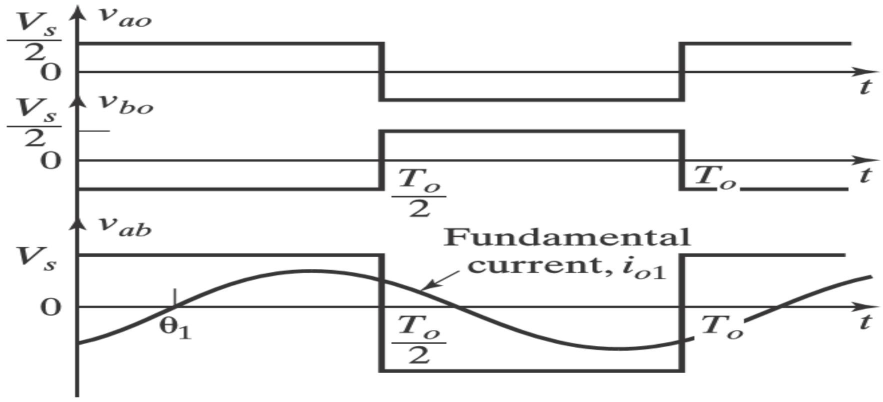

Figure 3.21. Waveform of Single-Phase Full-Bridge Inverter (Rashid, 2014).

The rms output voltage is:

$$V_o = \left(\frac{2}{T}\int_0^{To/2} Vs^2\, dt\right)^{1/2} = V_s \qquad (3.17)$$

Eq 3.17 can be extended to express the instantaneous output voltage in a Fourier:

$$V_o = \sum_{n=1,2,3}^{\infty} \frac{4Vs}{n\pi} \text{ sinnwt} \qquad (3.18)$$

And for n=1 Eq 3.18 gives the rms value of fundamental component as:

$$V_1 = \frac{4Vs}{\sqrt{2}\pi} = 0.90\ V_s \qquad (3.19)$$

When diodes (D1 and D2) conduct, the energy is fed back to the DC-Source and they are known as Feedback-Diodes.

In small UPS system with low level of DC Bus-bar, the inverter needs a transformer to step up the Output-Voltage of the Inverter to provide instant voltage by using PID controller for a nonlinear load and also to reduce the harmonics of the UPS output (Ramesh et al., 2014). The PID controller act as Voltage-Controller and DC-Offset canceller, as shown in (Figure 3.22).

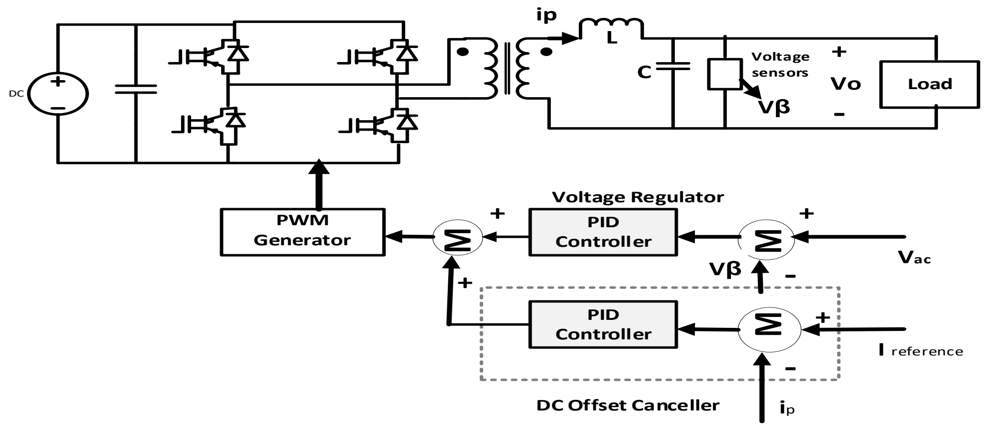

Figure 3.22. Block diagram of the conventional inverter with PID controller.

3.9. Transformer

In general, a transformer is used for step-down the input voltage in UPS to reduce the DC bus-bar voltage and also in output to step-up inverter voltage to supply the load. Using a Transformer in UPS design makes more losses, size and weight of the device. Nowadays in some UPS design doesn't use a transformer; therefore there are two types of UPS according to using a transformer.

3.9.1. Transformer-Based Technology

In a Transformer based UPS system, there is an Output-Transformer to boost the inverter-voltage to the required voltage at the UPS output. The Bridge or some time referred to "double-ended" inverter configuration can provide more than output power as in Single-Ended Inverter operating from the same Bus-bar Voltage (Green and Jackson, 2013).

A transformer as a DC-Component Output Isolator in Transformer-Based UPS systems is used to step the voltage up at the output of the Inverter to a Voltage compatible with the Utility. Furthermore, the Transformer isolates the DC-Circuit from the output load. The block diagram of Double-Conversion UPS system with Output-Transformer is showing in Figure 3.23. The Transformer is connected on the output of Inverter and not on the output of the UPS system. The DC-Component can be passing from the UPS to the load when one of the inverters IGBT faults or a bypass thyristor faults. In such kind of case, the Output-Inverter-Transformer in Transformer-Based UPS will isolate the inverter DC-Component from the load (Green and Jackson, 2013).

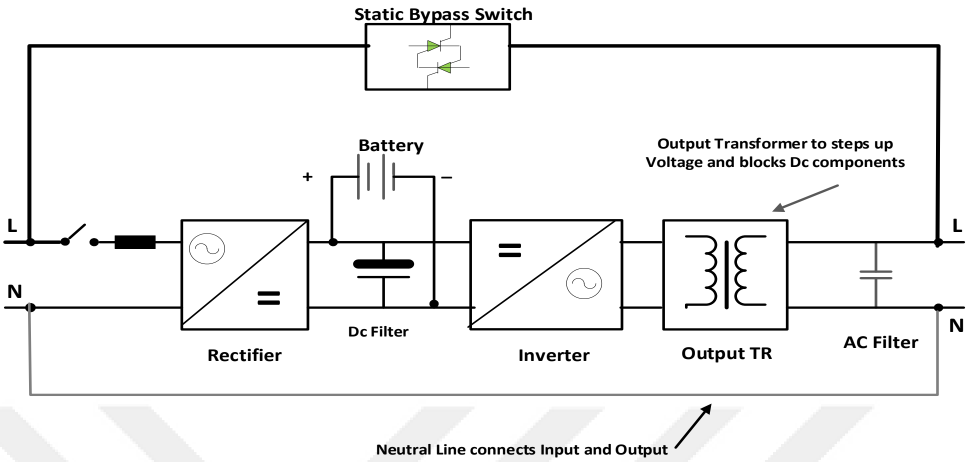

Figure 3.23. Transformer Based UPS system.

3.9.2. Transformerless Technology

As transformerless UPS technology (Figure 3.24) there is no transformer at the output of inverter, and in case of an Inverter IGBT fault, a DC-Component will be blocked at the output by (hardware and software) regulation. Transformerless-UPS-Technology handles the DC-Component through a Fully-Redundant EDCP (Electronic DC Protection) system so that the probability of a DC-Component appearing at the inverter-output is practically zero (Green and Jackson, 2013).

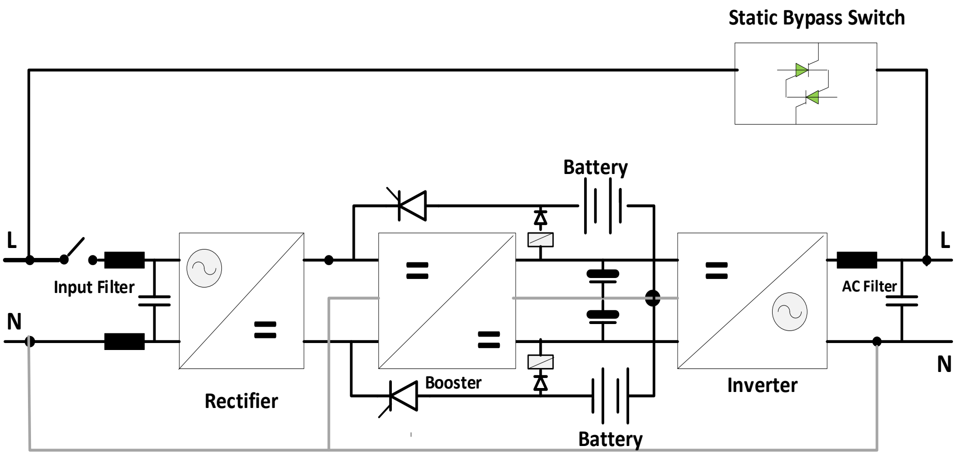

Figure 3.24. Block diagram of Transformerless UPS.

3.10. Output LC Filter

The low pass output filter is necessary to be added at the output of any H-Bridge inverter to obtain the fundamental frequency output. The main purpose of Low-Pass-Filter is to reduce Voltage-Ripple that comes from the inverter switching. The design of the LC filter below clarifies specification of dv/dt which is involved in much important role.

The filter should reduce high-frequency distortion of output voltage and control switching current. If we assume that the DC-Bus voltage is fixed at some value V_d, the rate of rising of the voltage is giving by:

$$\frac{dv}{dt} = \frac{Vd}{\sqrt{LC}} \tag{3.20}$$

To design an LC low pass filter for an inverter, there are many steps to be following, firstly, selecting the switching frequency to reduce filter size. High switch frequency is suitable, but the maximum frequency of solid-state switches and their dynamic losses limit the switching frequency. Secondly, selecting K factor, as standard K=15, but larger K factor causes reduction at switching frequency and little amplification at the fundamental frequency, and thirdly, selecting factor depends on the switching frequency and inductor ripple current (20% to 40% is an acceptable range for ripple current) (Ahmad et al., 2010).

Most of equipment is considered as Non-linear load and inject current and voltage harmonics in the main source, and causes more power losses in the network. Therefore reduction of harmonics is required to maintain power-quality and improving energy-efficiency by using Harmonic passive filter (Tali et al., 2016). There are different types of filter design topologies to reduction of a Harmonics; here we explain some of them:

3.10.1. Series–Connected AC-Reactor

It includes an Inductor connected in series with the nonlinear loads. It can pass Low-Frequency-Harmonics and provides High-Impedance to High-Frequency-Harmonic currents to limit their proliferation into the main source, (Figure 3.25).

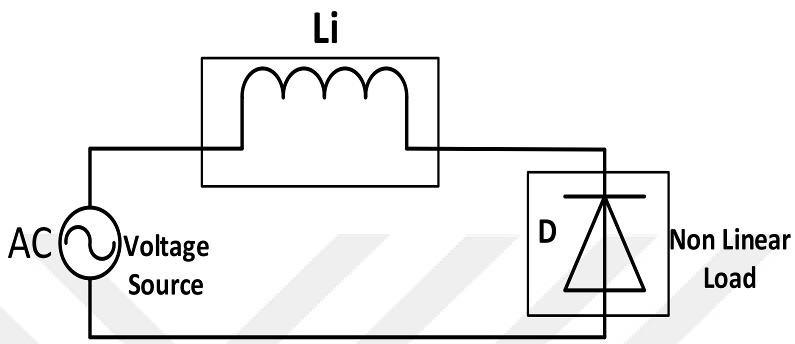

Figure 3.25. Series AC Reactor.

3.10.2. Shunt Passive-Filters

Shunt Passive-Filters (Figure 3.26), can be classified into three basic categories as follows:

1. Band-Pass-Filters (of Single or Double-Tuned).
2. High-Pass-Filters (of 1st, 2nd, 3rd) order or C-type).
3. Composite-Filters.

Figure 3.26. Block Diagram of Shunt passives filter.

3.10.3. Single Tuned Filters Design

It consist of (Inductor) Lf, (Capacitor) C_f and small damping (Resistor) R_f, all are connected in parallel with nonlinear loads to provide Low-Impedance paths for specific harmonic frequencies. It leads to absorb the Harmonic-Currents coming out from the load (Tali et al., 2016).

3.10.4. High Pass Filter Design

It is a Single-Tuned filter where the (L_h and R_h) elements are conducted in parallel instead of series. Such kind of design makes a Wide-Band filter having impedance at high frequencies limited by the resistance R_h.

Generally, LC Low-Pass-Filters placed between the load and the inverter. The filter inductor value (L) is calculated such that the voltage drop across the inductor is less than 3% of the inverter output voltage Vo.

$$2\pi \,.\, f.\, L \,.\, I_{Lmax} < 0.03\ V_o \tag{3.21}$$

Where I_{Lmax} is the maximum RMS (Root Mean Square) Load current, (f) is Output-Voltage- frequency 50Hz and ($V_{o)}$ is the RMS value of inverter Output-Voltage, the filter-capacitance value (C) is then calculated from the resonance relation as given in:

$$C = \frac{1}{(2\pi fo)^2 L} \tag{3.22}$$

Where (f_o) is Cut-Off-Frequency (Tali et al., 2016).

3.11. Bypass Line and Static Switch

UPS system like all other equipment could be under fault or overload that result in not working and it should maintain supply to the load. In such a case, the critical load can be provided from the inverter output or the AC main power. This could be done by Bypass-Line due to a static switch connected to the AC main power to the critical load directly. The static switch is an Intelligent-Switch that decides whether to use directly AC main power supply or UPSs inverter output voltage to supply the critical load, and this decision is made by UPSs Control-Logic which monitors all time the AC main supply and inverter-voltages, by controlling phase and frequency of UPS inverter to ensure that AC main power supply and inverter voltage are in phase with each other to avoid Break-Transfer time between the two supply sources. To do that the static switch has two inputs and one output to comprise the inverter and bypass voltage condition (Green and Jackson, 2013).

In On-line UPS topology, the critical load is completely isolated from the AC main line and the static switch has two operational states, the normal function ‘on UPS’ and ‘on bypass’, but in state of on-bypass, the device should alarm or warn the user because critical load is not protected any more from AC main power supply disturbance or interruption.

3.12. UPS Efficiency

The efficiency is one of the most important factors to reduce the power consumption and the operating cost by any user or organization. The efficiency of a UPS stills not the same by the different rates of the load as showing in Figure 3.27. Most of the system designer run the UPS under 80-90% of UPS full load capacity, and take 10-20% headroom for load expansion, because if the UPS above 100% overloaded, through the bypass-line connect the load directly to the main power without any protection for the critical load. Therefore, calculating the capacity and efficiency of the UPS and comparing it with nominal and maximal load is most important to design the UPS system in an organization.

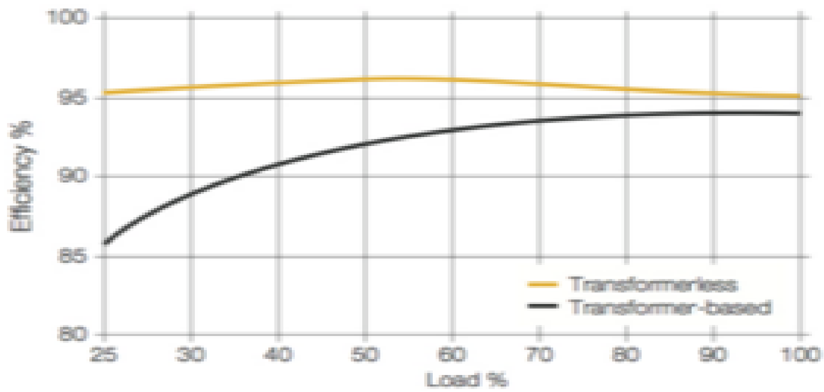

Figure 3.27. UPS Efficiency with difference level of Load (Green and Jackson, 2013).

3.13. Method of Design Structures

In this chapter, we explain each part of our design of Off-line, On-line and simple UPS systems. As we mentioned before to get nearly unity power factor and reduce input total distortion harmonics to less than 5%, we need to use an active PFC for input and another side for system output (load) too. Here we use a controlled boost converter topology and ACC method to put right the input PF and to fix the converter Output-Voltage. The boost converter boosts and fixes the voltage from 311 DC volts (after rectification by Full- bridge diode rectifier) to 400 DC volts. The DC Bus-bar of our designed system is 24 Volt, and the Battery bank is also 24 Volt (consist of 2x12 Volt batteries) to be supplied a load with approximately 800 VA.

Another side to reduce 400 DC V to 24 V to provide the battery charger, we need a step-down converter like a buck converter, but this ratio of voltage reduction around (24/400= 6%) is too much, therefore we use an Isolated Buck converter with high-frequency transformer to step down and fix the voltage as our battery and DC bus-bar required. To charge the battery we should put the charger voltage a little higher than DC bus-bar voltage, however, we put on 26.5V, and therefore the output voltage of Isolate buck converter is put on that voltage.

The second part of the design structure of any UPS system is the inverter side. To convert 24 DC volts from the battery, we need an inverter. Here we use a controlled full wave converter to get a 24 AC volt sinusoidal waveform. To step up this voltage we put a transformer with an output LC filter to supply the load.

In both of Off-line and On-line UPS system, the components are the same, just the connection of Bypass line and the time of inverter operating are different, because in Off line uninterruptible power supply system, the inverter operates only in case of AC main power failure, but in case of On line uninterruptible power supply system, the inverter will be in operation all the times and provide the load through the inverter and load will be isolate from the main source.

In third UPS design structure, for simple UPS we have a Boost converter without an additional circuit for PFC. In next sections; we explain all design systems and show the parameter of each component.

3.13.1. Off Line Uninterruptible Power Supply System

The Off-line UPS system as shown in Figure 3.28, is consist of two parts plus a bypass line. The Input side (Rectification and battery charging circuit) is connected to the AC main power source (220 V rms/ 50 Hz), and the Output side (output controlled Inverter with Transformer and LC filter) is connected with the Load (around 800VA). To be clearer we explain each part separately in details.

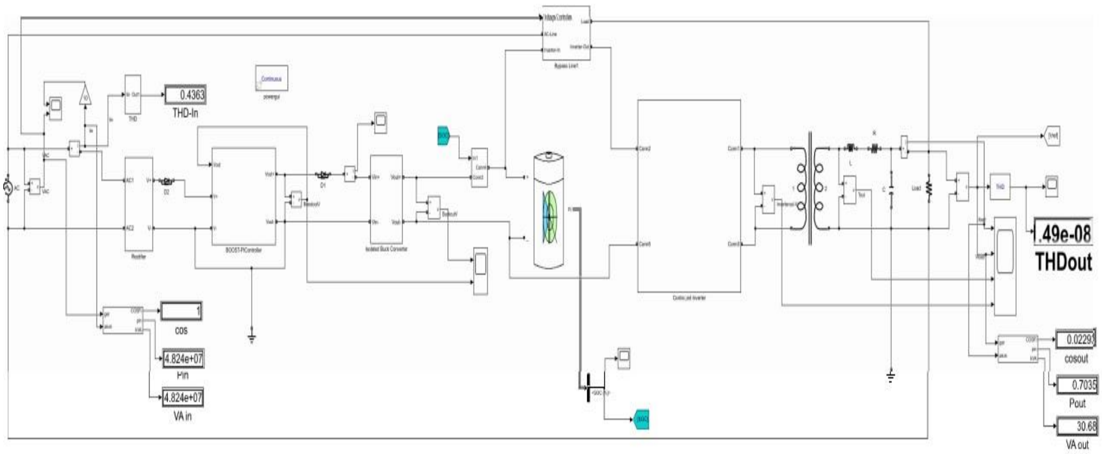

Figure 3.28. Design Structure of Off Line Uninterruptible Power Supply system with PFC.

3.13.1.1. Structure of Rectifier and Boost-Buck Converter of Off-Line UPS System

The Input side of our UPS system as shown in Figure 3.29, is contains of four subsystem included a Rectifier, controlled boost converter, Isolated Buck converter, battery charger and a Battery set. The AC main power is directly connected to a full-bridge rectifier to convert the AC sinusoidal waveform to a 311 DC volt. The rectifier provides a controlled boost converter to fix and boost the voltage to 400 DC volt, and to control shape of input signal to put right the PF and reduce the source current THD. To step up this voltage, the boost converter supplies an isolated buck converter to step down the voltage to 26.5 DC volts. The isolated buck converter is connected with Battery charge to charge the batter and protect the battery set from overcharging. In next sections we explain each circuit of this part with value of parameters of each component.

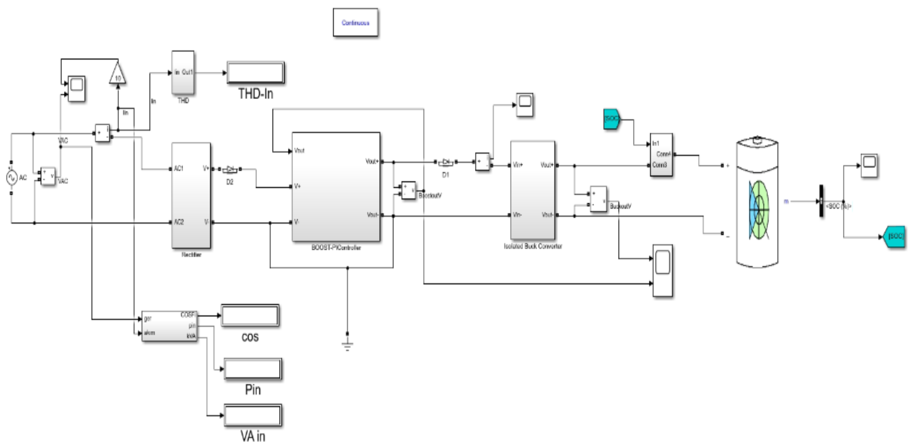

Figure 3.29. Design Structure of the Input side of Off-line Uninterruptible Power Supply System.

3.13.1.1.1. Full-Bridge Diode Rectifier

The rectifier circuit as shown in Fig. 3.30 is consist of four diode full bridge to rectify 311volt AC (220 V rms) to 311 volt DC, and then provide the controlled boost rectifier.

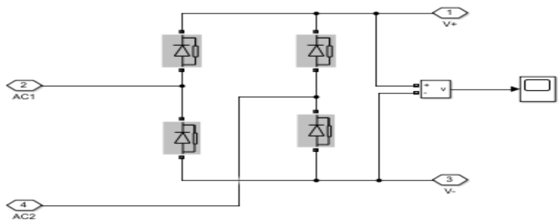

Figure 3.30. Full-bridge Diode Rectifier.

The parameters of all diodes are similar. The diode impedance is infinite on off-state mode, Resistance Ron= 0.001 Ohms, (Forward-Voltage) V_f (V) = 0.6 V, (Snubber-Resistance) Rs= 50000 Ohms and (Snubber Capacitance) Cs (F) = 250e-9.

3.13.1.1.2. Controlled Boost Converter for Input PFC

The controlled boost converter (Figure 3.31), consists of an IGBT switch transistor, inductance coil (L), Resistor (R), Diode D, voltage sensor, Current sensor, transistors gate control circuit and a Capacitor. The input of the circuit will be supplied with 311 DC volts, and through duty cycle of the switch it steps up the voltage to 400 DC volts. The duty cycle of the transistor gate will be controlled by a controlled circuit to correct input PF and reduce source current THD by using average current control method.

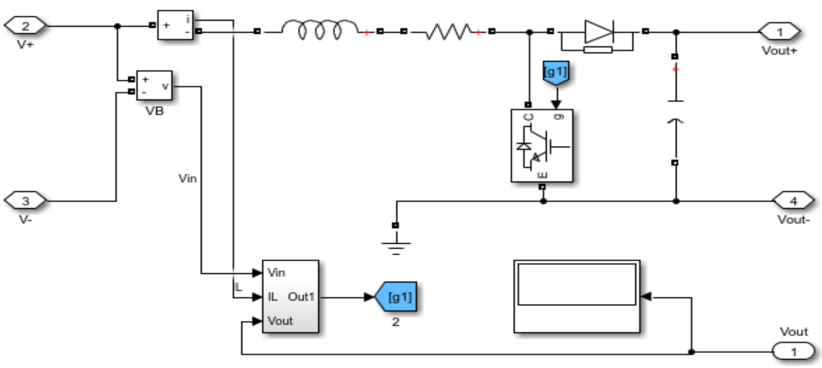

Figure 3.31. Block diagram of Controlled boost converter for UPS input PFC.

The parameters of these elements are: L = 3e-3 H, R = 0.3 Ohms, C = 1000 e-3 F with initial voltage of 310V. The IGBT parameters are; (Internal Resistance) R_{on}= 1e-

3 Ohms; (Snubber-Resistance) R_s= 1e6; (Snubber-Capacitance) C_s= INF. For the diode, the diode impedance is infinite on off-state mode; Resistance R_{on}= 0.0001 Ohms; (Forward- Voltage) V_f (V) =0.8V; (Snubber-Resistance) Rs= 50000 Ohms; and (Snubber-Capacitance) C_s (F) =250e-9.

The Control block as shown in Figure 3.32, consists of two PI controllers. One of them to fix the output voltage by comparing the circuit output voltage V_{out} and a reference voltage V_{ref}. (we put on 400V), and the error of first PI will be multiplied with the input voltage V_{in}, to be compared with input current by second PI controller to find the delay angle in between input current and voltage, and finally both of PI controller correct the output-voltage and input-current shifting to get a nearly unity PF and therefore reducing the input THD. Here we use 10 KHz frequency for gate switching of the transistor and it will be duty of transit the circuit to boost the voltage.

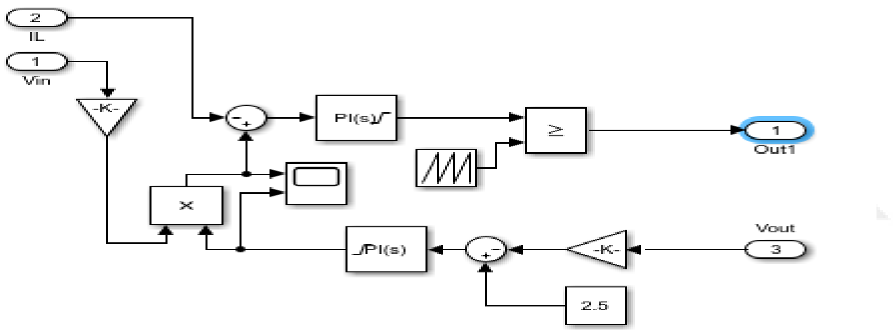

Figure 3.32. Off-line Power factor control circuit.

The parameters of the control circuit are: Repeating sequence parameters; time value = [0 0.0001] = 10 KHz; Output value = [0 1]. The Voltage Reference: 400V, gain block (K_{out}) = 2.5/400 and K_{in} = 1/311.

The current PID controller compares output of voltage PI controller with main Input current shape to find error of delay in between the inputs current and the voltage. The parameters of the current PI controller are shown in Table 3.1.

Table 3.1. Parameters of the current PI controller in designed Boost converter

Parameter	Value
Time Domain	Continuous time
Source	internal
Proportional (P)	1.7
Integral (I)	200
Output saturation Limit / Upper saturation limit	0.98
Output saturation Limit / Lower saturation limit	0.02
I product/ Inherit via internal rule	Minimum = -1 ; Maximum = 1

The voltage PID controller compares the output-voltage with the reference-voltage and then sends errors to the current PI-controller. The parameters of voltage PI-controller are as in (Table 3.2).

Table 3.2. Parameters of the Voltage PI controller in designed Boost converter

Parameter	Value
Time Domain	Continuous time
Source	internal
Proportional (P)	1.3
Integral (I)	210
Output saturation Limit / Upper saturation limit	20
Output saturation Limit / Upper saturation limit	0.01
I product/ Inherit via internal rule	Minimum = -10 ; Maximum = 10

3.13.1.3. Isolated Buck Converter

The control boost converter provides directly 400 DC volt to the Isolated Buck converter. This voltage is too high for our 24V bus-bar, and normally buck converter couldn’t step down the voltage with this ratio, therefore we should use an Isolated Buck converter included a high frequency transformer. The circuit as shown in Figure 3.36, is consisting of four (Mosfet) as transistor switches, high frequency Transformer (T) with double winding, two diodes (D), Inductor (L), Resistor (R), Capacitor (C), and control circuit which content one PI controller, two Sawtooth generators, and two relays.

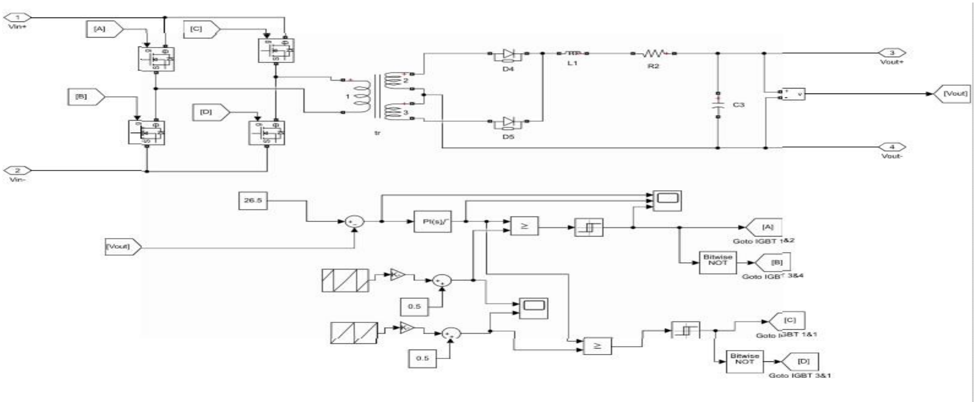

Figure 3.33. Block Diagram of Isolated Buck converter with control circuit of UPS system.

The output voltage will be contrasted with the reference-voltage (26.5 V) to fix and correct the error of the output-voltage through the duty cycle of the Mosfets. The PI controller sends the pulse to all transistors after correction of the output error. The parameters of elements in the circuit are as in (Table 3.3).

Table 3.3. The parameters of Isolated Buck converter of UPS system,

Parameter	**Value**
Inductor (L)	1e3 H
Resistor (R)	0.35 Ohms
Capacitor (C) with an initial voltage of 24V	470 e-6 F
Both Sawtooth generators: frequency	20 KHz
Phase degree	180
Sample time	0
Both relay: Switch on point	eps
Switch off point	eps
Output when on	1
Output when off	0
All four Mosfet: FET Resistance Ron	0.001 Ohms
Internal-diode-resistance R_s	0.001 Ohms
Internal-diode-forward-voltage	0 V
Initial current Ic	0 A
Snubber-Resistance R_s	50000 Ohms
Snubber-Capacitance C_s (F)	250e-9
Both diodes: Diode impedance	Infinite on off-state mode.
Resistance R_{on}	0.00001 Ohms
Forward-Voltage V_f (V)	0.5
Snubber-Resistance Rs	50000 Ohms
Snubber-Capacitance Cs (F)	250e-9

The parameters of PI controller and the high frequency transformer of Isolated Buck converter are as in (Table 3.4).

Table 3.4. The parameters of PI Controller and High Frequency Transformer of UPS system,

Parameter	**Value**
PI controller: Time Domain	Continuous time
Source	Internal
Proportional (P)	0.15
Integral (I)	100
Output saturation Limit / Upper saturation limit	0.49
Output saturation Limit / Upper saturation limit	0.01
I product/ Inherit via internal rule	Minimum = -1 ; Maximum = 1
Parameter	**Value**
Parameters of the High Frequency Transformer	
Nominal-Power and frequency "P_n(VA) F_n(Hz)"	1000 20000
Winding-1 Parameter "V_1 (V_{rms}) R_1(ohm) L_1(H)"	395 0 0
Winding-2 Parameter "V_2 (V_{rms}) R_2(ohm) L_2(H)"	27 0 0
Winding-3 Parameter "V_3 (V_{rms}) R_3(ohm) L_3(H)"	27 0 0
Magnetization-resistance and inductance "R_m(ohm) L_m(H)"	Inf 0.001

3.13.1.4. Battery-Charging Circuit

The battery-charging circuit includes a control circuit, Inductor L, and a diode (Figure 3.34). The control circuit of the charger is consists of an ideal-switch and a Relay (Figure 3.35). The ideal switch cut off the charging process to avoid overcharging of the batteries. The Inductor reduces the ripple of current through the charger to supply the battery with a smooth charging current. The parameters of the diode and the relay are listed in the (Table 3.5).

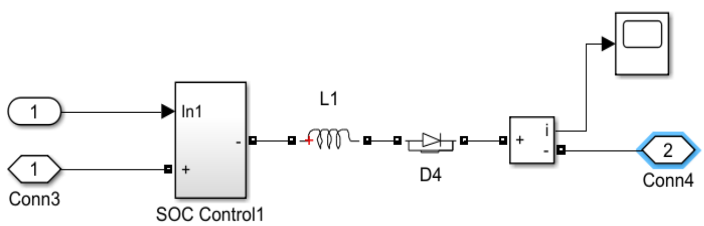

Figure 3.34. Design Structure of Battery-charging circuit of UPS system.

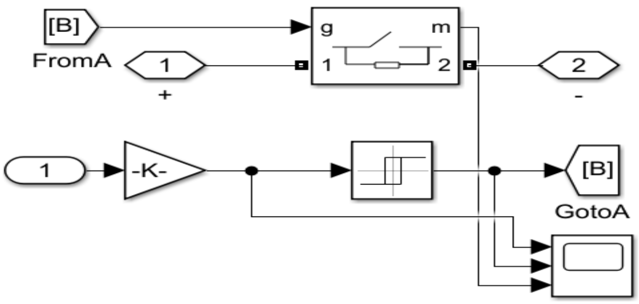

Figure 3.35. Design Structure of Battery-charging controller of UPS system.

Table 3.5. The parameters of the battery charging circuit of UPS system,

Parameter	Value
Inductor (L)	1e-4 H
Parameters of the Diode: The Diode impedance	infinite on off-state mode
Resistance Ron	0.00001 Ohms
Forward-Voltage Vf (V)	0.5 V
Snubber-Resistance Rs	50000 Ohms
Snubber-Capacitance Cs (F)	250e-9
Parameters of the Ideal switch	Initial state (o for 'open', 1 for 'closed' =1
Internal-resistance Ron	0.000001 Ohms
Snubber-resistance Rs	1e8 Ohms
Snubber-capacitance Cs	Inf F
Parameters of the Relay	
Switch on point	1
Switch off point	0
Output when on	0
Output when off	1

3.13.1.1.5. Battery Set Parameters

The battery bank consists of two batteries lead-acid; each one is 12 Volt with 7Ah. Both batteries will be connected in series to get 24 Volte and 14 Ah. If the AC main power is there, the battery will be fully charged to be ready to provide the inverter in case of any main power interruption. The totally power of fully battery set is about 336 VA for an hour, but the UPS power is designed to supply a load with 800 VA, it means the battery set have enough power to supply the load for about 20 minutes. Parameters of battery like in the Table 3.6.

Table 3.6. The parameters of Battery of UPS system,

Parameter	**Value**
Nominal-Voltage	24 V
Rated-capacity	14 Ah
Initial-state-charge	50%
Battery-response time	0.00001 Seconds
Discharge-parameters of the Battery	
Maximum-capacity (Ah)	14.5833
Cut-off -Voltage (V)	18
Fully-charged-voltage (V)	26.1216
Nominal-discharge current (A)	2.8
Internal-resistance (Ohms)	0.017143
Capacity(Ah) at nominal voltage	4.3439
Exponential-zone "Voltage (V), Capacity (Ah)"	6.5 13 32.5

3.13.1.2. Design structure of Output Inverter of Off-Line UPS System

The output side of our UPS system as shown in Figure 3.36, is contain of three parts included a controlled Inverter, output Transformer, and a LC filter. The input port of the inverter is connected through a bypass switch with the battery set to supply the load in case of AC main source interrupting. The Bus-bar voltage of the system is 24 Volts, it means the inverter will convert the battery set DC voltage to 24 AC voltages and then the Transformer will step up the voltage to 311 volts to supply the load through the LC filter. The filter will absorb noises coming from inverter switching and harmonics form nonlinear load.

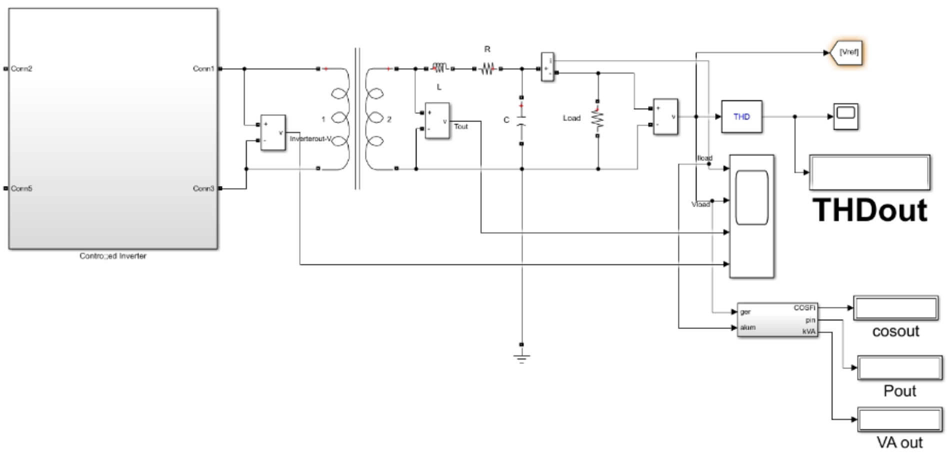

Figure 3.36. Block diagram of Design structure of Off-Line UPS System - Output Inverter.

3.13.1.2.1. Controlled Inverter

The inverter consists of four similar IGBT switch transistors connected as H-bridge topology to invert 24 DC volt supplies from the battery to 24 AC volts and forward to the step-up transformer to provide the load through LC filter with 311 AC volts. The switching of the circuit will be controlled from a gate control circuit. The design topology of the Inverter is shown in the Figure 3.37. The two input ports of the circuit are connected directly with the battery, and the two output ports connected directly with the output transformer. All IGBT switch transistors are similar and have parameters as: IGBT (Internal-Resistance) R_{on}= 1e-3 Ohms; (Snubber-Resistance) R_s= 1e6 Ohms; (Snubber-Capacitance) C_s= INF.

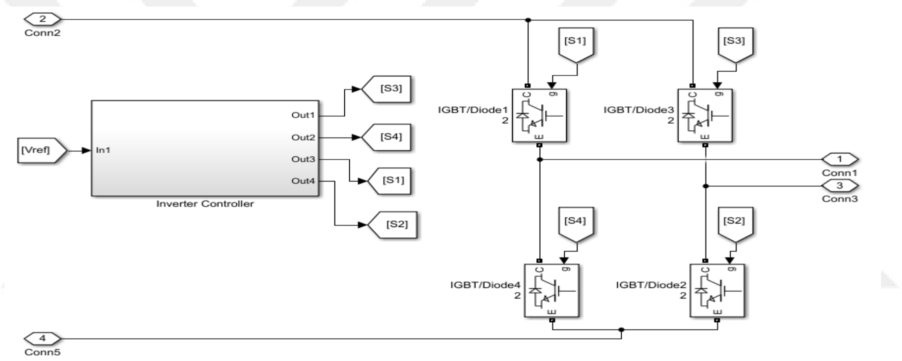

Figure 3.37. Output Inverter Circuit of Off-Line UPS with H-bridge topology.

The gate of the switch Transistors gets duty cycle signal from Inverter controller to convert a DC-voltage to an AC sinusoidal waveform voltage. The control circuit as shown in Figure 3.38 consists of a control loop block, PI controller, and saturation Block.

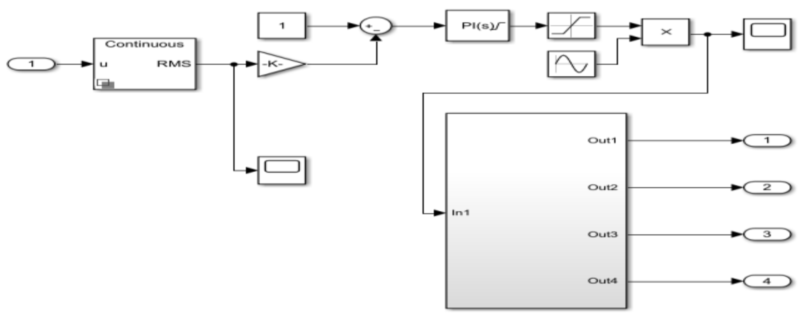

Figure 3.38. Circuit diagram of the Inverter controller of Off-Line UPS System.

The Loop circuit is responsible to create the duty cycle pulses for the gates of transistors of the inverter. The cycle frequency is generated by Sawtooth Generator with 20KHz. The designed circuit of the loop circuit as below (Figure 3.39).

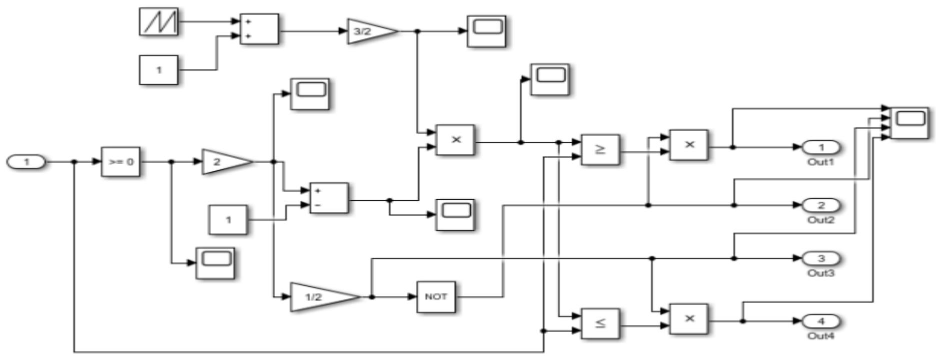

Figure 3.39. The Circuit Diagram of loop circuit for Inverter controller of UPS System.

The parameters of both circuit components are list in Table 3.7.

Table 3.7. Parameters of Inverter controller and Loops circuit of Off-Line UPS System,

Parameter	**Value**
Inverter PI controller:	
Time Domain	Continuous time
Source	Internal
Proportional (P)	25
Integral (I)	100
Output saturation Limit / Upper saturation limit	2.95
Output saturation Limit / Upper saturation limit	0.01
I product/ Inherit via internal rule	Minimum = -3 ; Maximum = 3
Parameter	**Value**
Sine wave Parameters:	
Amplitude	1
Bias	0
Frequency rad/se	2P*50
Phase rade	0
Sample time	0
Saturation block	Upper-limit = 2.5 / Lower-limit = 1.5
Sawtooth Generator Parameters:	
Frequency	20e3 Hz
Phase rade	0

3.13.1.2.2. Output Transformer

The output transformer step up the inverter output voltage from 24 V to 311 V AC. It is also isolate the load from inverter switching noises. Output transformer parameters are as below (see Table 3.8).

Table 3.8. Output transformer parameters of Off-Line UPS system,

Parameter	Value
Output Transformer	
Nominal Power and frequency "P_n(VA) F_n(Hz)"	1000 50
Winding 1 Parameter "V_1 (V_{rms}) R_1(ohm) L_1(H)"	24 0 0
Winding 2 Parameter "V_2 (V_{rms}) R_2(ohm) L_2(H)"	400 0 0
Magnetization resistance and inductance "R_m(ohm) L_m(H)"	Inf Inf

3.13.1.2.3. Off-Line Output LC Filter

The output LC filter is to filter inverter switching noises and a current harmonics distortion occurs due nonlinear load. The parameters of LC filter are; Inductor (L) = 3e-3 H.; Resistor (R) = 0.00001 Ohm; and Capacitor C = 1e-6 F.

3.13.1.3. Bypass Line circuit of Off Line Uninterruptible Power Supply System

Bypass-line’s circuit diagram for Off line Uninterruptible Power Supply system (Figure 3.40) include a switch to control the gate of both ideal switches in the circuit. When the AC line source is available; the first switch is ON and supplies load straight from AC-line source. If the AC-line voltage is below 160 V (RMS), the first switch will be OFF, and the second switch will be ON and then start to operate the Inverter to supply the load from battery stored power.

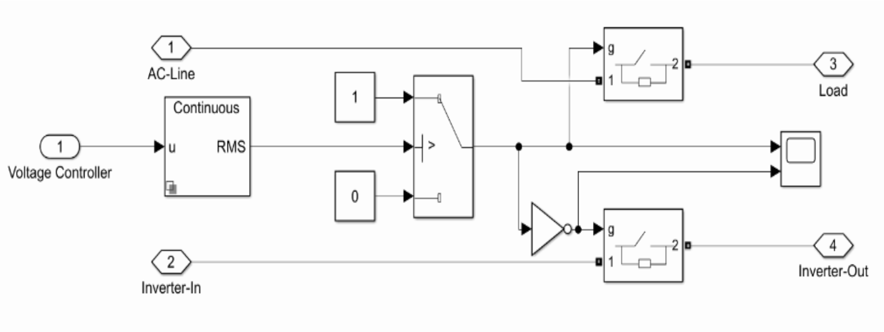

Figure 3.40. The Circuit Diagram of Bypass-Line of Off-line UPS system.

The parameters of bypass-line circuit are below (see Table 3.9).

Table 3.9. The parameters of Bypass line circuit components of Off-line UPS system,

Parameter	Value
Parameters of the Ideal switch	Initial state (o for 'open', 1 for 'closed' =1)
Internal-resistance R_{on}	0.00001 Ohms
Snubber-resistance Rs	1e8 Ohms
Snubber-capacitance C_s	Inf F
Parameters of the Switch	
Criteria for passing first input	U2 > threshold
Threshold	160
Output signal attributes	Minimum 230; Maximum 330

3.13.2. On Line Uninterruptible Power Supply Design Structure

The ON Line Uninterruptible Power Supply system as shown in Figure 3.41, is like our Off line Uninterruptible Power Supply design structure, the different is that all parts are connected and operated continuously when the AC main source available or not. The load will be isolated from the AC main source and it will be supplied only by a pure sine wave from the inverter, because the input part charges the battery and provide the inverter in the same time, and energy stored in the battery will be used in case of AC main source interruption without any switching time to change over from AC main source to the battery.

The Parameters of most components are same as in Off-line UPS System; here we mention as in Table 3.10, only the components those are changed.

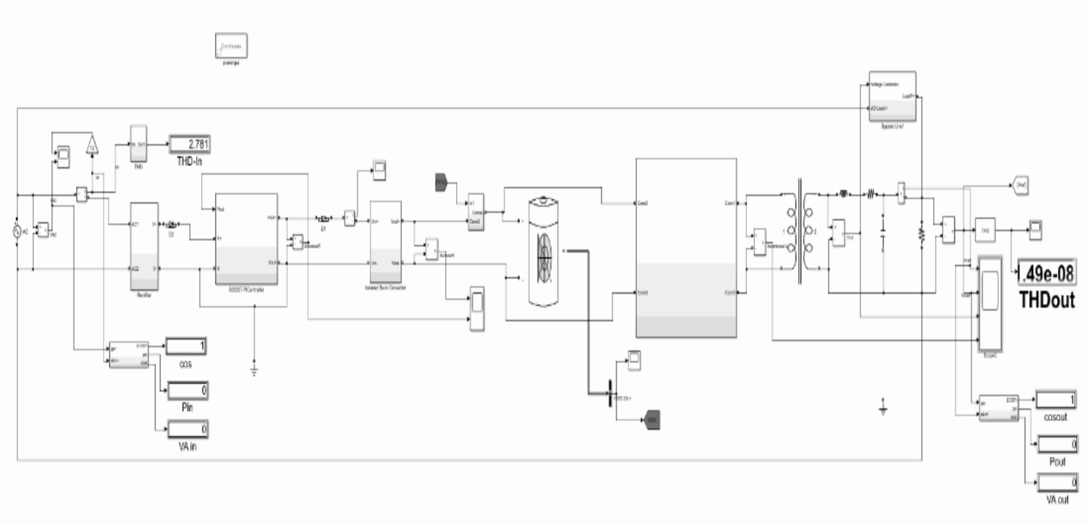

Figure 3.41. On-Line UPS system design structure.

Table 3.10. The parameters of only components are changed for On-line UPS system,

Parameter	Value
Isolated Buck Converter	
Inductor (L)	1e3 H
Resistor R (R)	0.55 Ohms
Capacitor (C)	1470 e-6 F
On-line Output LC Filter	
Inductor (L)	3e-3 H
Resistor R (R)	0.001 Ohms
Capacitor (C)	1e-3 F

3.13.2.1. Bypass Line for Online UPS

The design structure of Bypass line in online Uninterruptible Power Supply system (Figure 3.42) is different as in Off-Line UPS. In case of any fault of the UPS device the switch will change over to connect the load directly with the AC main source just to avoid the interruption of power, but the load will not be protected from any abnormality of AC main source. The switch threshold comparison is put on, when the control gate of the switch is above 180 (rms volt) then switch will be OFF, and the load will be supplied from the inverter output. In case of partly or totally fail of UPS as a device, the switch will be opened (on state “ON”) and the load will be provided straight from the AC-line source.

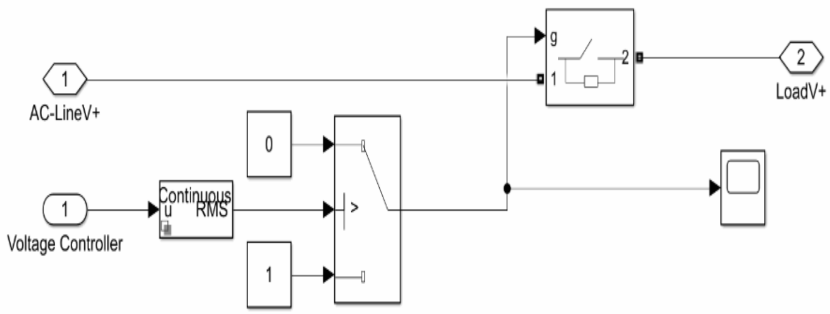

Figure 3.42. Block Diagram of Bypass-line of Online Uninterruptible Power Supply system.

3.13.3. Simple Uninterruptible Power Supply System

The simple Uninterruptible Power Supply system includes input transformer, simple circuits (Full-bridge rectifier, battery charger, Battery, Inverter without controlling) and output Transformer. We design this UPS system just to compare it with other two systems and find how PFC affects the input and output voltage and current. The design structure of simple UPS is like in Figure 3.43. In general, the system consists of two parts, the Input side (Input Transformer, Rectifier, Battery charger, and battery set) and output part (Inverter and output Transformer).

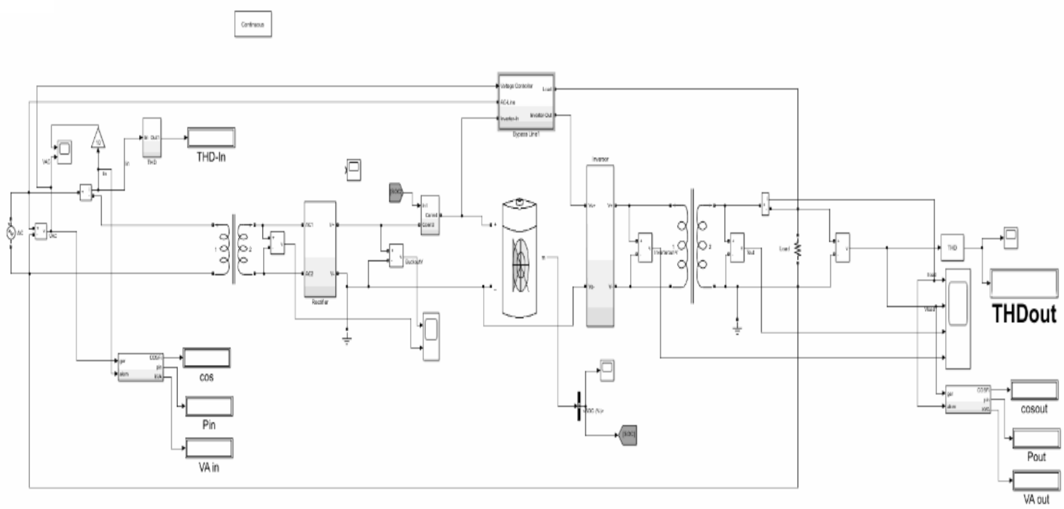

Figure 3.43. Circuit Diagram of Simple Off-Line UPS system.

3.13.3.1. Input Transformer and Rectifier of Simple UPS Design Structure

As shown in Figure 3.44, the Input side of the UPS contains of an Input Transformer to step down the AC main source voltage (311 V) to 24 AC volt to be supplied the H-Bridge rectifier. The rectifier will provide a 24 DC volt to the battery charger to charge the batteries.

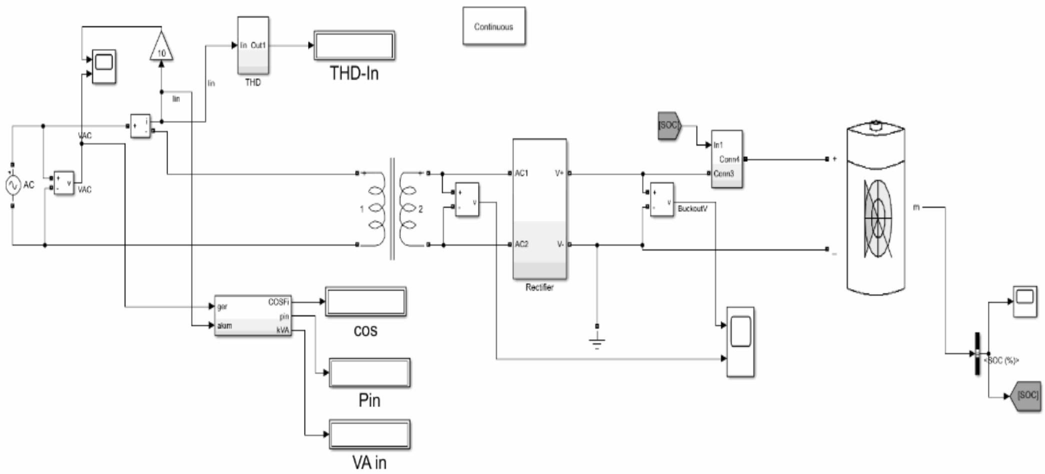

Figure 3.44. Circuit Diagram of Input side of the simple UPS system.

3.13.3.1.1. Input Transformer

The Input transformer is connected directly with AC main power source to step downs 311 volts AC main voltage to 26 AC volts, because of battery set and the Bus-bar are 24 volts. The parameters of the input transformer are as below (see table 3.11).

Table 3.11. Parameters of Input Transformer by simple UPS System,

Parameter	Value
Input Transformer	
Nominal Power and frequency "P_n(VA) F_n(Hz)"	1000 50
Winding 1 Parameter "V_1 (V_{rms}) R_1(ohm) L_1(H)"	311 0 0
Winding 2 Parameter "V_2 (V_{rms}) R_2(ohm) L_2(H)"	26 0 0
Magnetization resistance and inductance "R_m(ohm) L_m(H)"	Inf Inf

3.13.3.1.2. Full-wave H-Bridge rectifier with a capacitor

The design structure of H Bridge rectifier (Figure 3.45) is exactly like in Off-line UPS, we only added an output capacitor to reduce ripple of DC voltage. We put the capacitor value on 1e-3 F with an initial voltage of 24v.

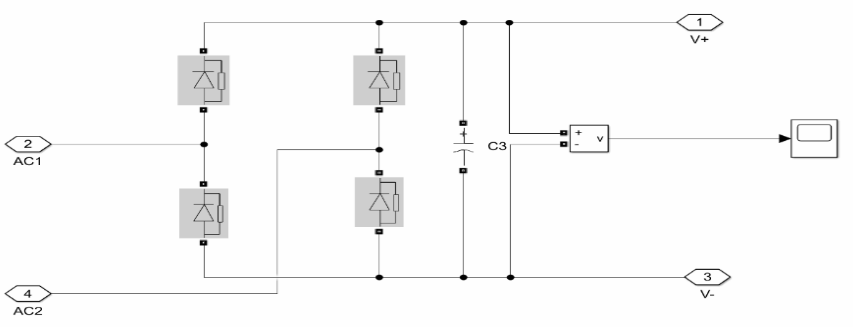

Figure 3.45. Circuit diagram of rectifier of simple UPS System.

The Battery-charger and the specification of the battery are the same as in Off-line or On-line UPS system.

3.13.3.2. Output Inverter and Transformer of Simple UPS Design Structure

The second part of this design structure is output inverter and output transformer, as shown in Figure 3.46. The inverter converts the 24 volt battery DC voltage to 24 AC volts and then provides the load through the step up transformer. This circuit is very simple UPS system without any additional circuit for PFC or filtering the noises, just the output transformer will help a little to isolate a DC voltage occur due switching of the inverter.

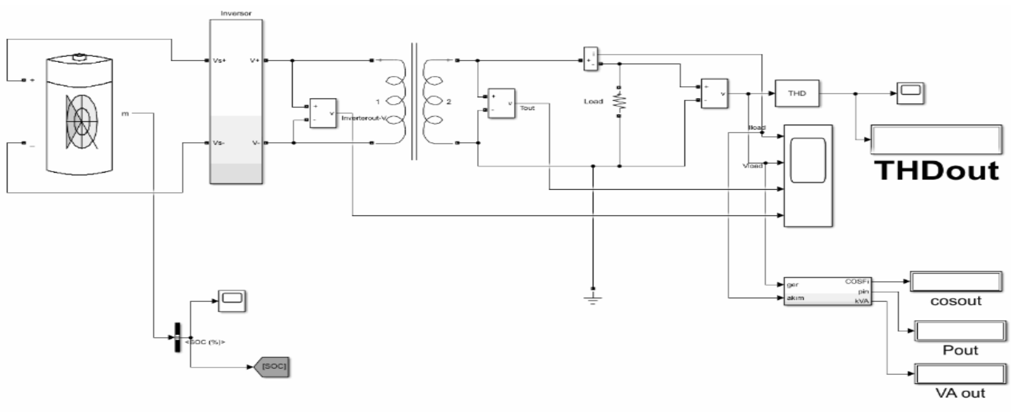

Figure 3.46. Circuit Diagram of Inverter side of Simple UPS System.

3.13.3.2.1. Output Inverter of simple UPS system

The Output inverter (Figure 3.47) is included of four Mosfet switch transistors and a pulse generator circuit (Figure 3.48). This circuit will change the DC-voltage from battery to AC-voltage to supply to the load through a step up transformer.

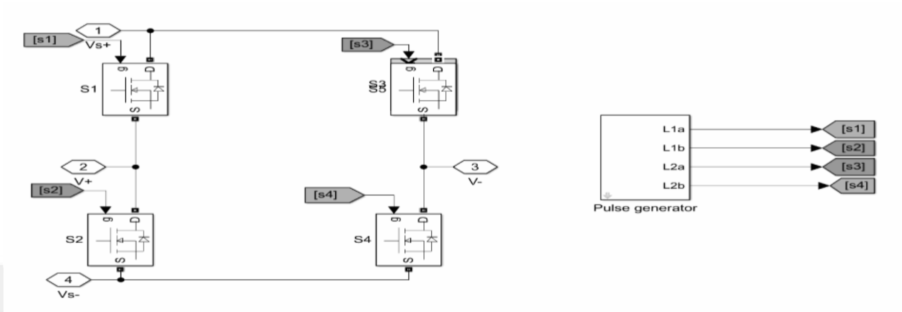

Figure 3.47. Circuit Diagram of Output Inverter for the Simple UPS System.

The Parameter of Mosfet switch transistor (all four Mosfet are similar) and the pulse generator are as below (see table 3.12).

Table 3.12. The parameters of MOSFET and Pulse Generator of Simple UPS System,

Parameter	Value
All four Mosfet: FET-Resistance Ron	0.01 Ohms
Internal-diode-Inductance $_{Lon}$	0
Internal-diode-resistance R_d	0.001 Ohms
Internal-diode-forward-voltage V_f(V)	0 V
Initial current Ic (A)	0 A
Snubber-Resistance R_s	1e5 Ohms
Snubber-Capacitance C_s (F)	Inf
Dead Time	10e-6
Pulse width (angle)	180
Pulse Generator	
Amplitude	5
Period (Secs)	1/50
First Pulse-Generator	
Pulse-Width (% of period)	((pw/360)*100)
Phase-delay	0
Second Pulse-Generator	
Pulse-Width (% of period)	((pw/360)*100)-(2*deadtime/period)*100
Phase-delay	period/2+deadtime

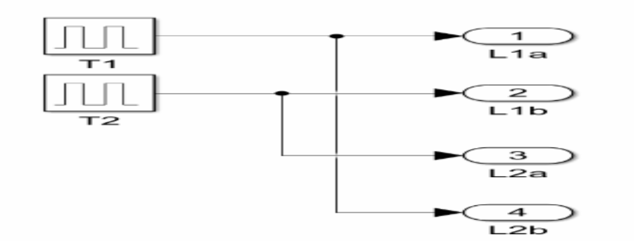

Figure 3.48. Circuit Diagram of Pulse Generator of Simple UPS System.

3.13.3.2.2. Output Transformer

The Output transformer step up the inverter output voltage (24 volts) to 311 volts is to provide the load in case of AC main power source is interrupted. We can see in Table 3.13 all parameters of output Transformer.

Table 3.13. Parameters of the output Transformer of Simple UPS System,

Parameter	Value
Output Transformer	
Nominal Power and frequency "P_n(VA) F_n(Hz)"	1000 50
Winding 1 Parameter "V_1 (V_{rms}) R_1(ohm) L_1(H)"	24 0 0
Winding 2 Parameter "V_2 (V_{rms}) R_2(ohm) L_2(H)"	500 0 0
Magnetization resistance and inductance "R_m(ohm) L_m(H)"	Inf Inf

3.13.1.2.3. Bypass-Line of the Simple UPS system

The design and functionality of Bypass line of simple UPS system as shown in Figure 3.49, it is exactly the same as in Off-Line UPS system, and the parameters are also the same.

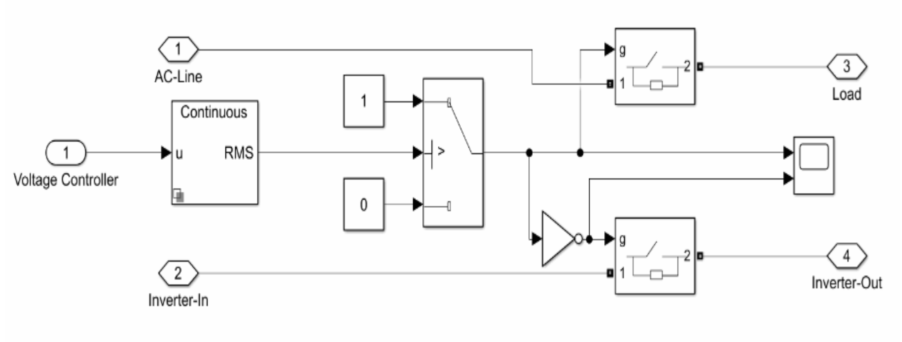

Figure 3.49. Circuit Diagram of Bypass Line of Simple UPS System.

4. RESULTS

In this chapter, we analyze and compare the results which we obtained from our design modulations. Our aims were improving input/output power factor and reducing the Total Harmonic distortions. We made all design structures for three types of UPS systems with Matlab-Simulink software program and after running the modules, we got input waveform and power factor with THD percentages. Another side of the output voltages, we got also the same as for the input. We compare results of all three types of our designed UPS systems in terms of Input / Output waveform and Power factor with THD, then we compare them with some available UPS systems in the market, to see what we have done and how were the results of our design structures.

When we improve input power factor and reduce THD, we reduce losses of the UPS as a device; because less power factor and high THD ratio mean more losses. Otherwise, it is true, by using active PFC, the efficiency of UPS as a device will be lower, especially by on-line UPS systems, because all circuits will be in operation all the time, also when the AC main power is available. By using passive PFC, the highest PF ratio reach around 0.9, it means around 10% of the input power going as losses. This amount of energy is approximately the same amount of energy which is used to operate the UPS system as a device, especially in case of full load providing. But the problem of lower efficiency is when the UPS system provides a half load and the power losses through the device will be relatively higher, and the power factor and THD will be less effective.

4.1. Result of Off-line UPS system

The input current and Voltage waveform as shown in Figure 4.1 are sinusoidal sine waves. The input current is around (8 A) by battery charging and full load, the input PF is around one, and the THD is smaller than 5% (3% to 4% as shown in Figure 4.2) as required.

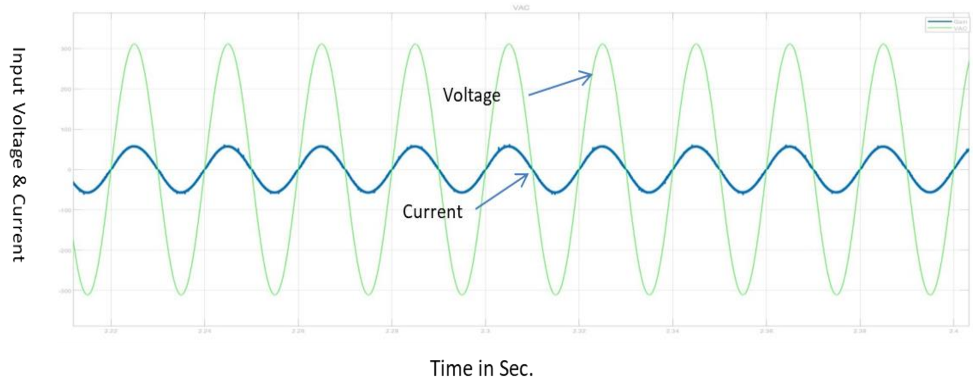

Figure 4.1. Input current and voltage waveform by the off-line UPS system.

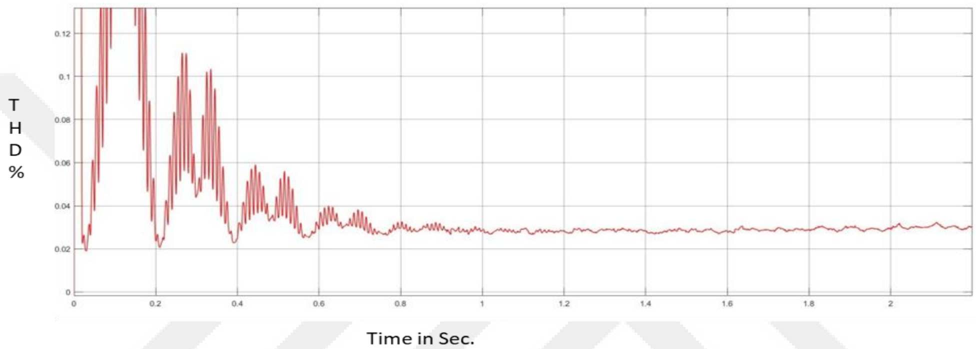

Figure 4.2. The THD of Input AC line (less than5%) by Off-line UPS system.

The output waveform of boost and isolated buck converters are fixed as required with a little ripple voltage (Figure 4.3).

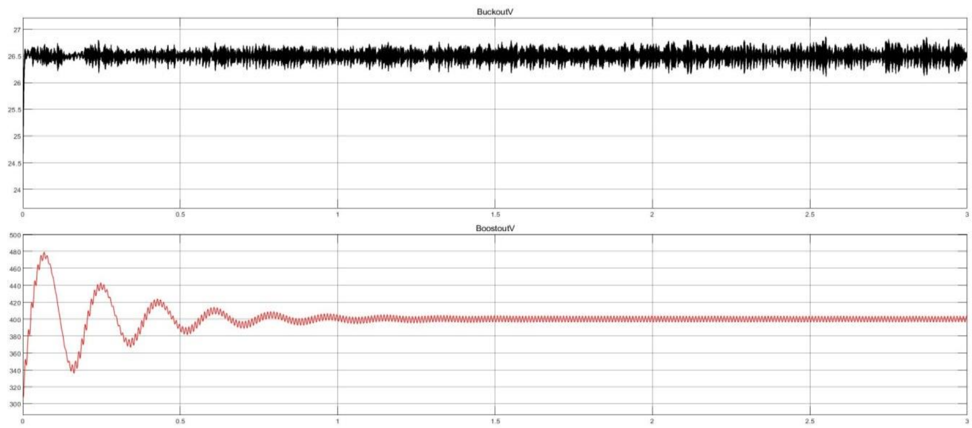

Figure 4.3. The output-voltage of Boost and Isolated Buck converters in case of Off-line UPS system.

The battery-charger provides energy to the battery. Battery will be charge smoothly (Figure 4.4). Battery-charging-current is also smoothly coming down (Figure 4.5).

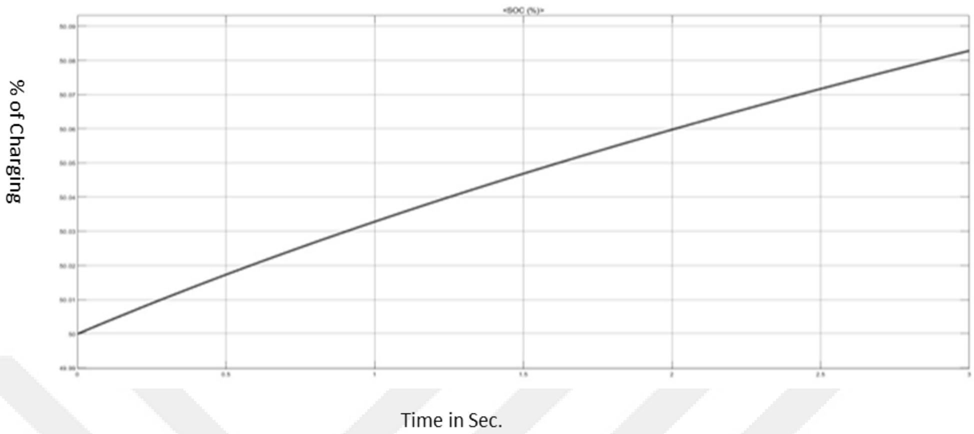

Figure 4.4. Battery charging process of Off-line UPS system.

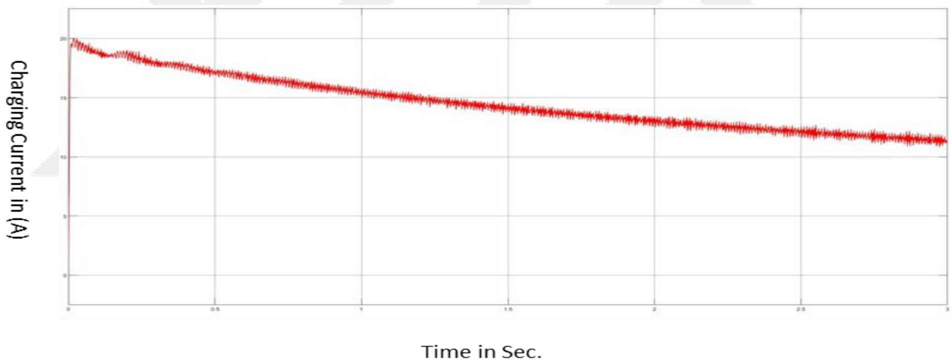

Figure 4.5. Battery charger current of Off-line Uninterruptible Power Supply system.

The second part of the Uninterruptible Power Supply device is the inverter side. The inverter takes energy from the battery and converts 24 DC volts to 24 AC volts. Then it provides the step-up transformer directly to make 311 AC volts, and then the load will be supplied through the LC filter. The LC filter absorbs any noises or harmonics produced by the inverter switching process. Figure 4.6 clears the output-waveform of the transformer and the output-waveform of the system which is supplied to the load.

The power factor of system outputs is around one and output-THD ratio is smaller than 5% as required, by Full Load (R=62 Ohms).

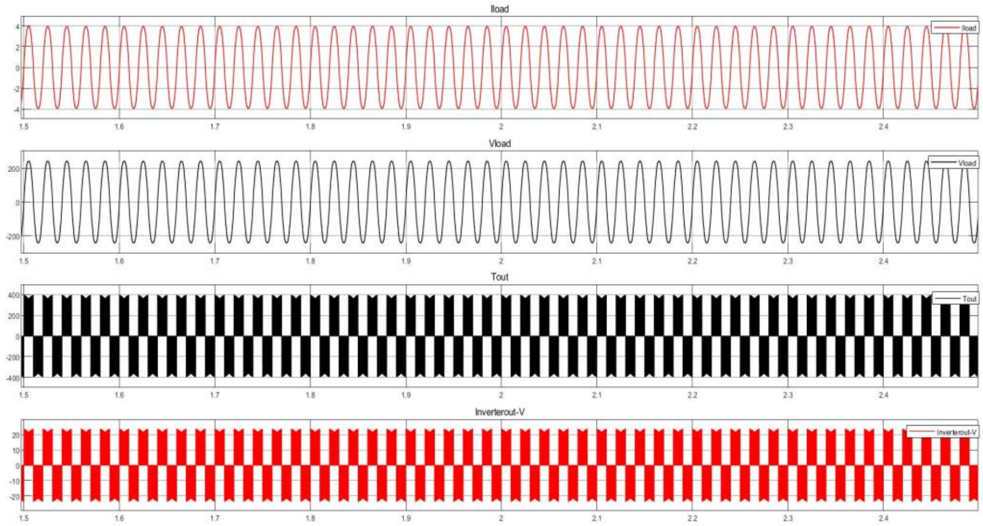

Figure 4.6. Off-line UPS- output waveforms by Full-load.

We run the same design circuit for Half-load (R= 100 Ohms) the results were similar as shown in Figure 4.7. The power factor for the output is nearly unity and the THD ratio was under (5%) as required.

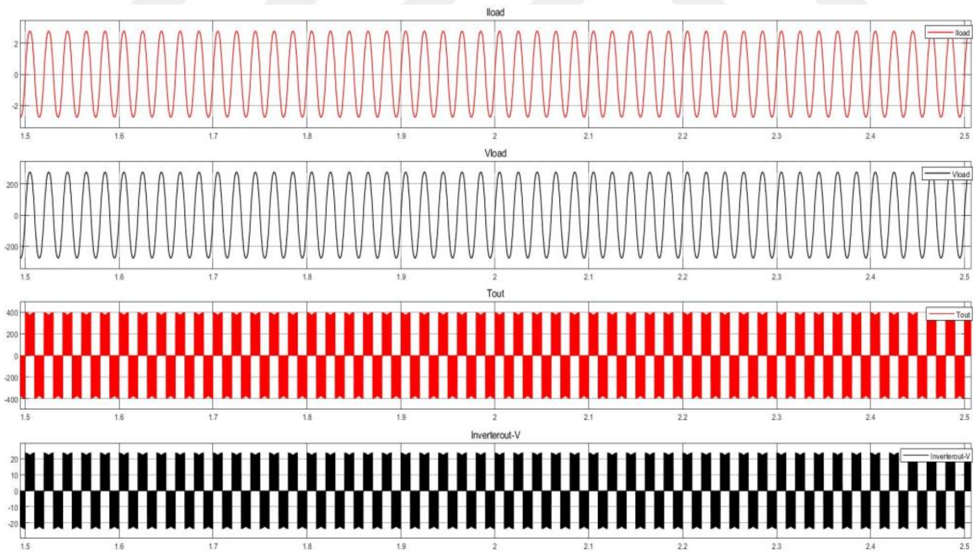

Figure 4.7. Off-line UPS- output waveforms by Half-load.

We repeated the same steps with quarter-load (R=200 Ohms), and the result were as required, nearly unity Power factor and less than (5%) of THD, (Figure 4.8).

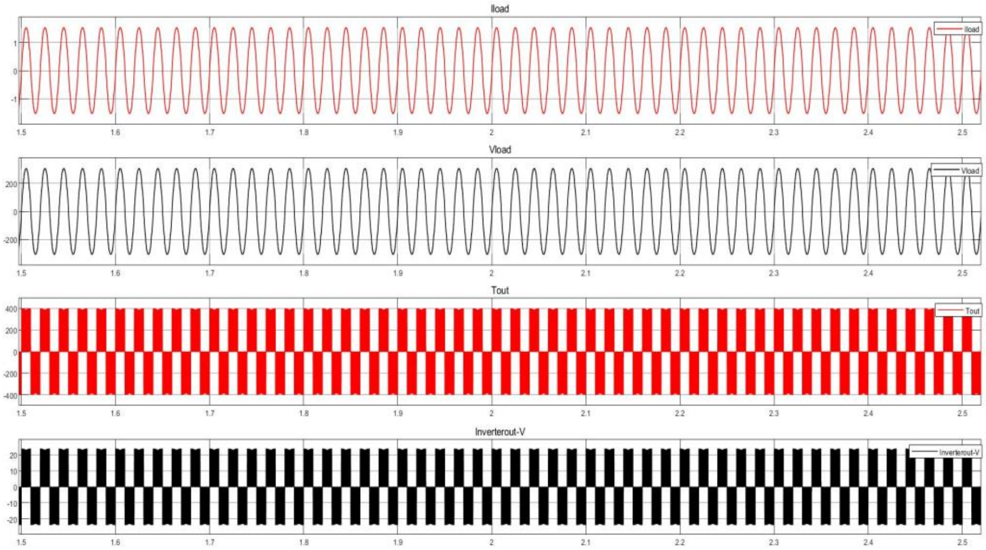

Figure 4.8. Off line UPS output-waveform by Quarter-load.

In Table 4.1 we see the power factor in all cases is nearly unity, it means the load doesn't affect the output voltage and the THD in all cases still under 5%. The efficiency will be decreased by half and quarter load because the amount of power consumption for the device is the same in all case.

Table 4.1. Off line Uninterruptible Power Supply system with load variation,

Off line UPS System	**Full-load 62 Ohms**	**Half-load 100 Ohms**	**Quarter-load 200 Ohms**
Input-Line THD (%)	4.3	4.3	4.3
Output Load THD (%)	4.58	3.18	3.84
Input Power VA	1695	1695	1695
Output P (VA)	1348	972.5	560.4
Load Current (A)	4.5	3	1.6
Input Cos θ	1	1	1
Output Cos θ	1	1	1

4.2. Results of On-line Uninterruptible Power Supply system

It is also like off line Uninterruptible Power Supply system, input (current and voltage) waveform of the On line UPS system are sinusoidal sine waves (Figure 4.9). The input current is around (8 A) by full load and battery charging at the same time together. The Input PF is around unity, and the THD is smaller than 5% (3% to 4%) as required, (Figure 4.10).

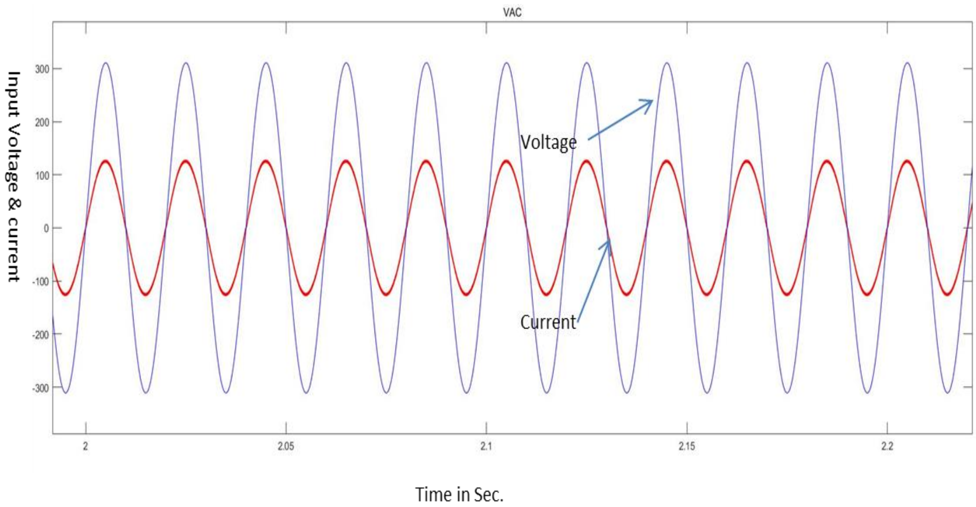

Figure 4.9. Sinusoidal input-voltage and current waveform by On-line UPS system.

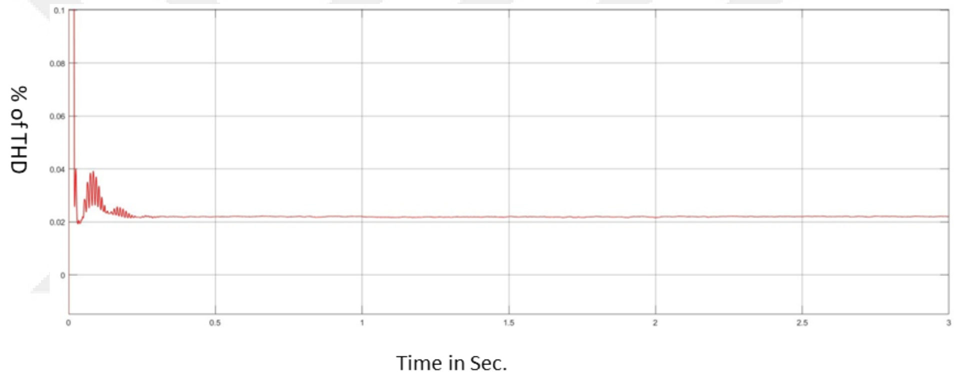

Figure 4.10. The THD of the input Ac line (less than5%) by the On-line UPS system**.**

The output waveform of boost is 400V (with +/- 3) and the isolated buck converters are fixed on 26.5 V (with 1 volt ripple) as required. Figure 4.11 shows the output voltage waveform of both converters.

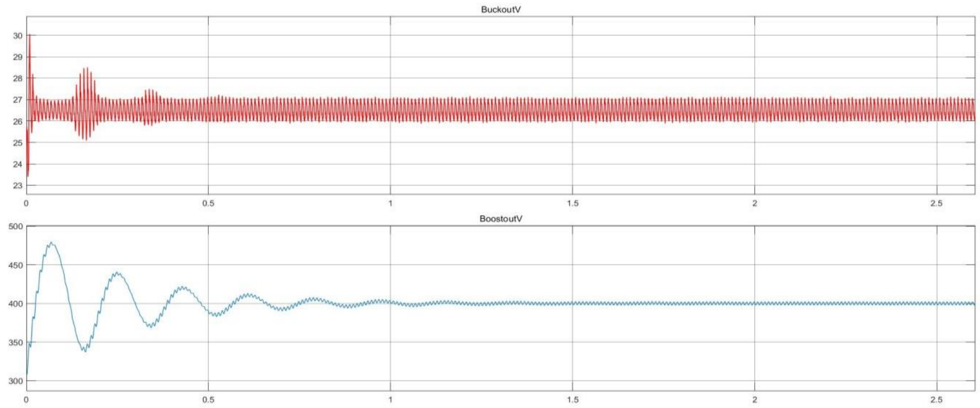

Figure 4.11. The output voltage of Boost and Isolated Buck converters in case of Off-line UPS system.

The battery-charger provides energy to the battery. The battery will be charged smoothly. The charging- process is shown in figure 4.12, and the current of battery charger is shown in figure 4.13.

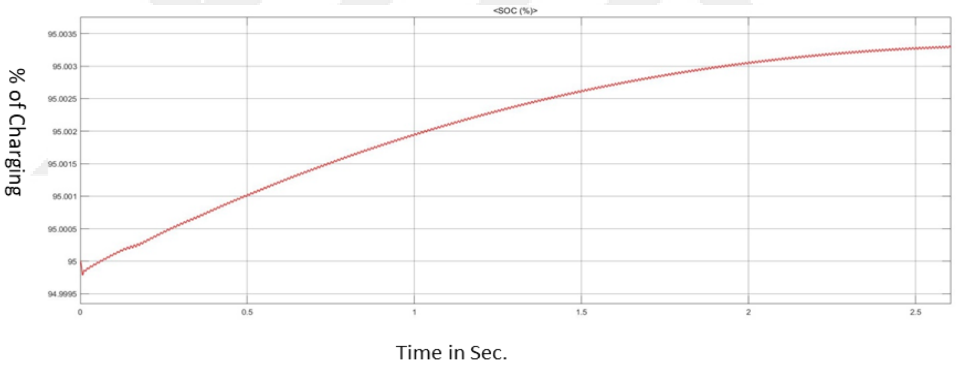

Figure 4.12. Battery charging process of On-line UPS system.

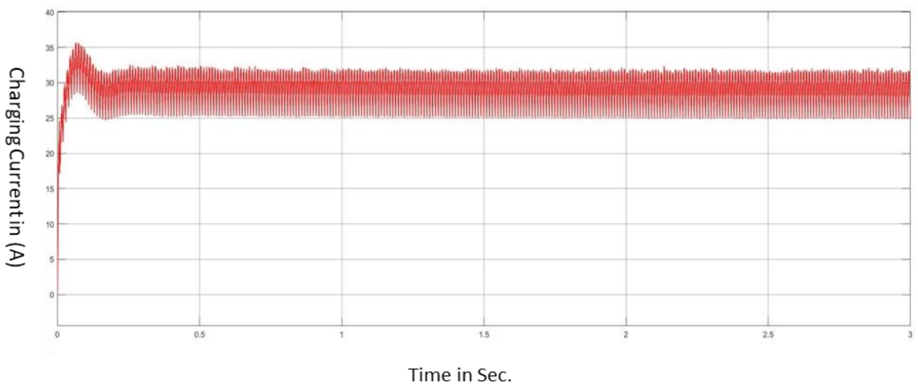

Figure 4.13. Battery charger current of the on line UPS system.

The second part of our UPS device is the inverter side. The inverter takes the energy from the battery and changes 24 DC volt to 24 AC volts. Then it provides the step-up transformer directly to make 311 AC volts. Then through the LC filter it protects the load from any noises or harmonics produced by the inverter switching process. Figure 4.14 shows output waveform of the transformer and output waveform of the system which is supplied to full load. PF of the system-outputs is around unity and the output THD ratio is less than 5% as required.

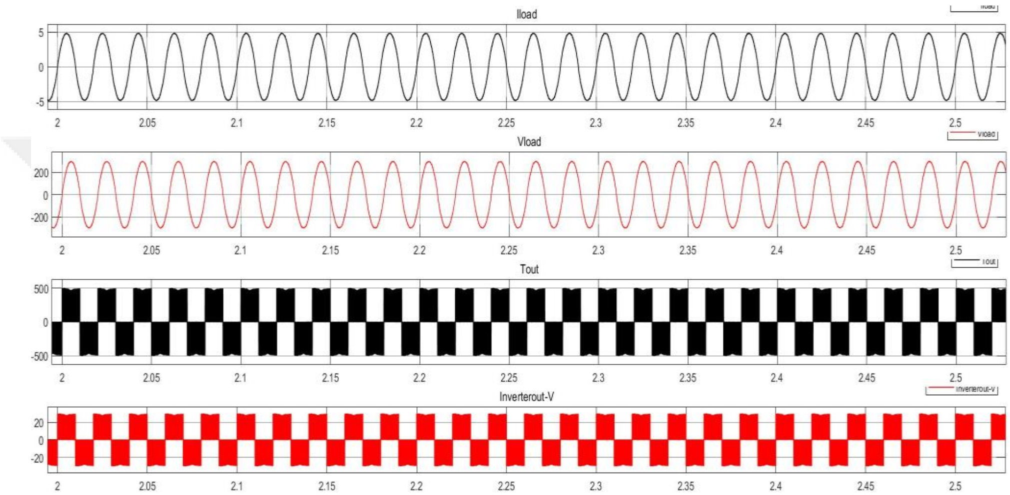

Figure 4.14. On-line UPS – Output waveform Full-load.

We change the Load to half for the same on-line design circuit and we see the results as shown in Figure 4.15. The output PF is also close to unity and the (THD) also is under 5%.

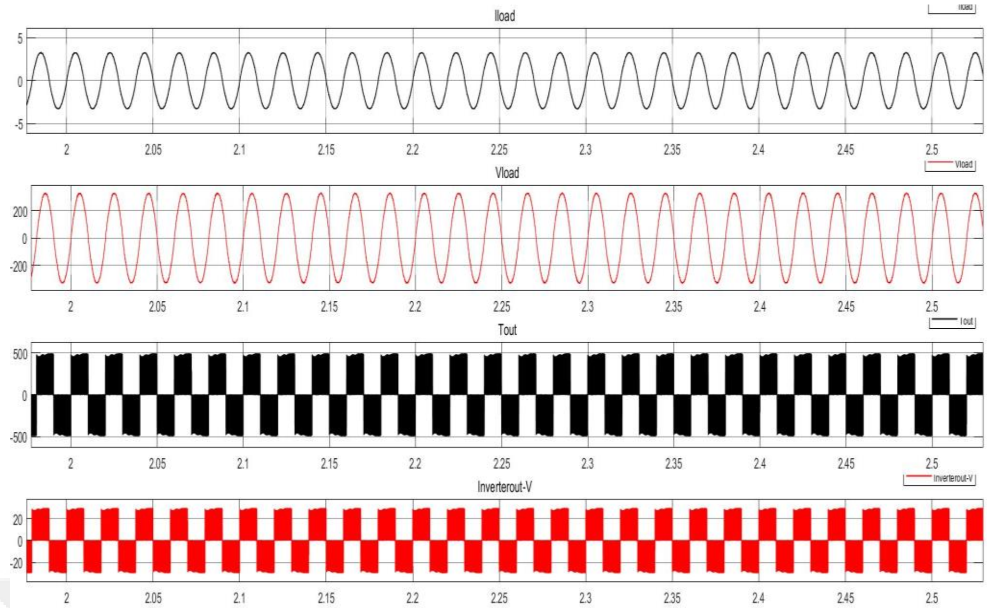

Figure 4.15. On-line UPS – Output waveform Half-load.

Also we got similar result by quarter load for the same design structure of our On-line UPS device as in figure 4.16. input and output PF ratio still close to unity and the input and output THD ratio also still fewer than 5% as required.

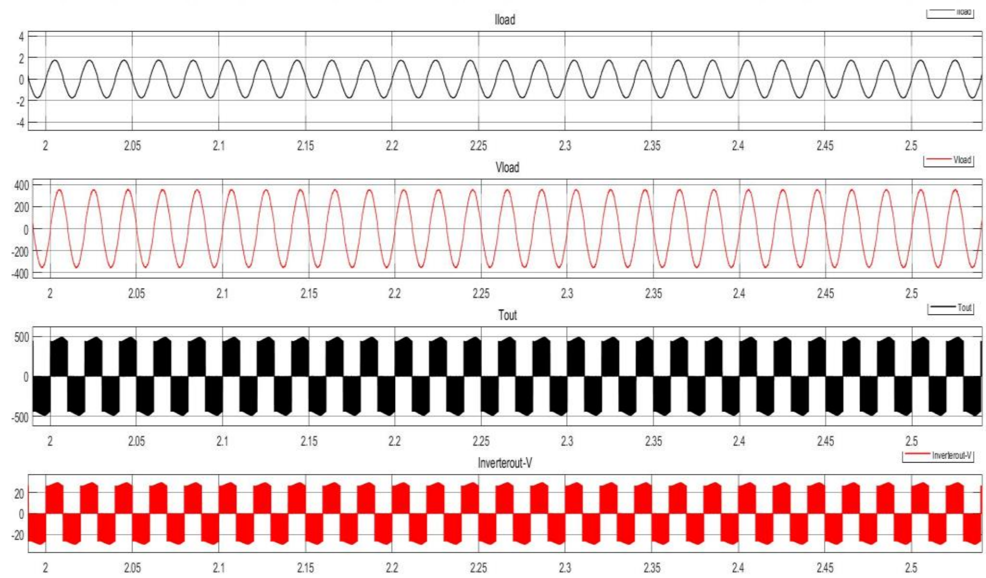

Figure 4.16. On-line UPS – Output waveform Quarter-load.

Here in Table 4.2, we see the comparison in between all cases of load variation without affecting the THD and the power factor of Input and output of the design circuit. Only the efficiency is affected when we reduce the load because the consumption of the device stills the same.

Table 4.2. Online UPS system with load variation,

Online UPS System	**Full-load 62 Ohms**	**Half-load 100 Ohms**	**Quarter-load 200 Ohms**
Input-Line THD (%)	2.5	3.3	3.9
Output Load THD (%)	3.8	2.3	2.7
Input Power (VA)	3175	2361	2089
Output Power (VA)	1528	1090	679
Load Current (A)	5	3.3	1.85
Input Cos θ	1	1	1
Output Cos θ	1	1	1

4.3. Results of Simple UPS System without any PFC

The simple UPS system designed without any additional PFC circuit. The input (current and Voltage) waveforms as shown in Figure 4.17 are non-sinusoidal sine wave and the THD is very high because of the rectifier. The input current is around (8 A) by full load and battery charging in the same time, the Input PF is pure, the THD is more than 200% (300% to 400% as shown in Figure 4.18). In practice such kind of UPS will be designed with a low-pass filter (LC) to reduce the THD and improve the power factor, but it never reaches more than 0.6 of power factor and with high THD around 30%).

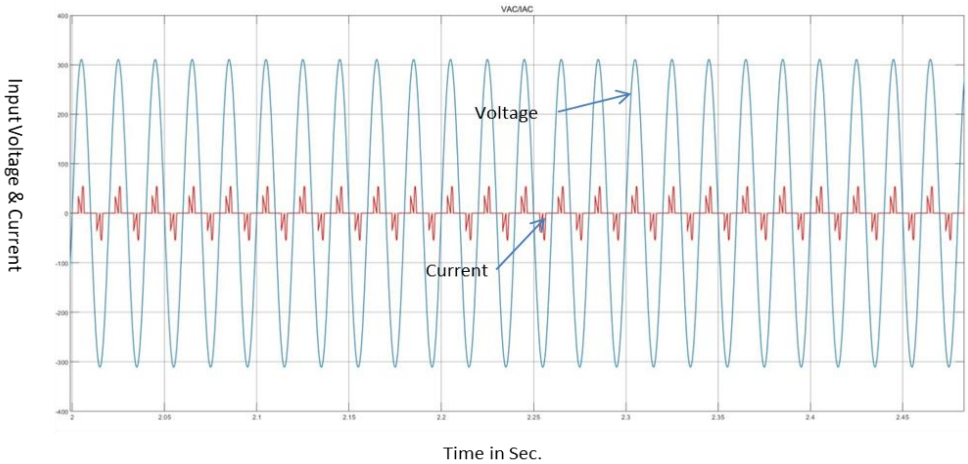

Figure 4.17. Input voltage and current waveforms of simple UPS system without PFC circuit.

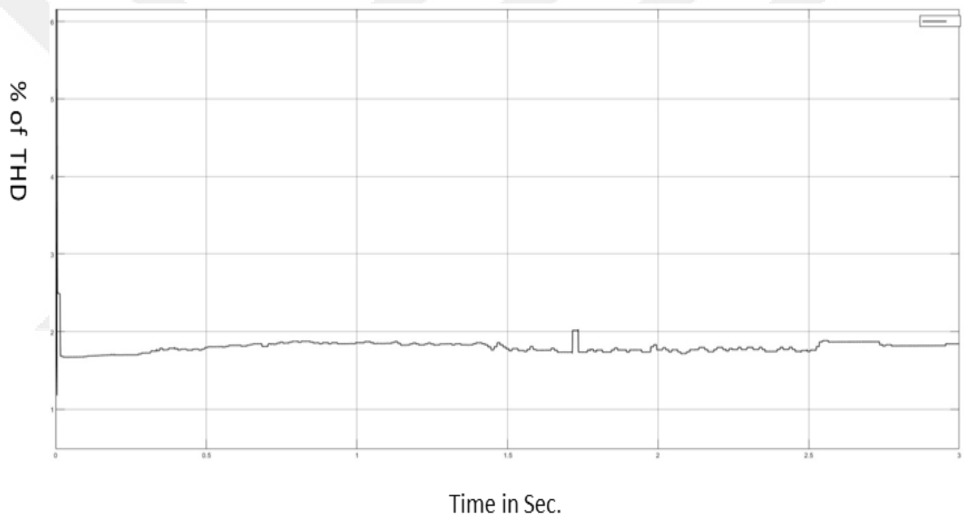

Figure 4.18. The THD of Input Ac line (more than 200%) by simple UPS system without PFC circuit.

The rectifier and the Buck converter output voltages as shown in Figure 4.19 are fixed as required with a little ripple of voltage.

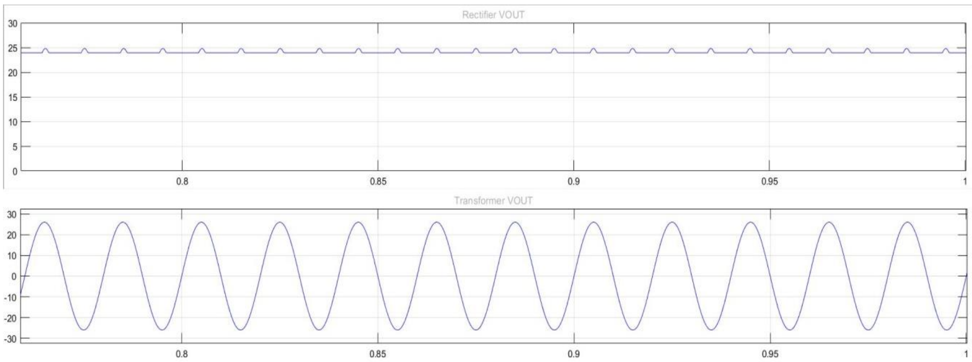

Figure 4.19. Output voltage waveform of rectifier and buck converter in simple UPS system without PFC.

The battery-charger provides the energy to the battery (Figure 4.20). The battery will be charged smoothly (Figure 4.21).

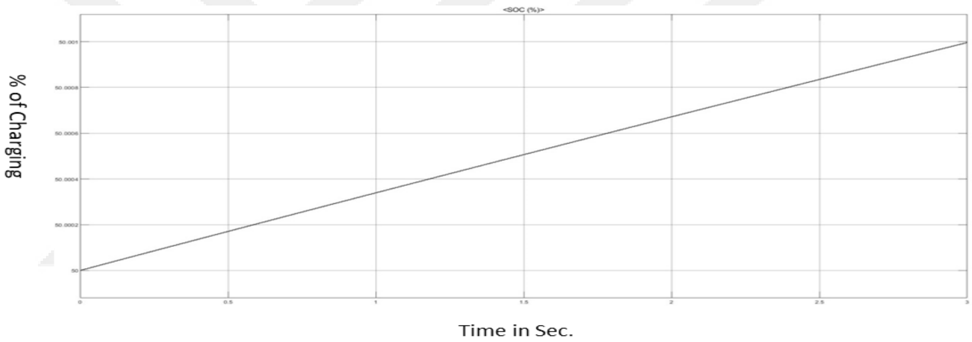

Figure 4.20. Battery charging process of simple UPS system without PFC.

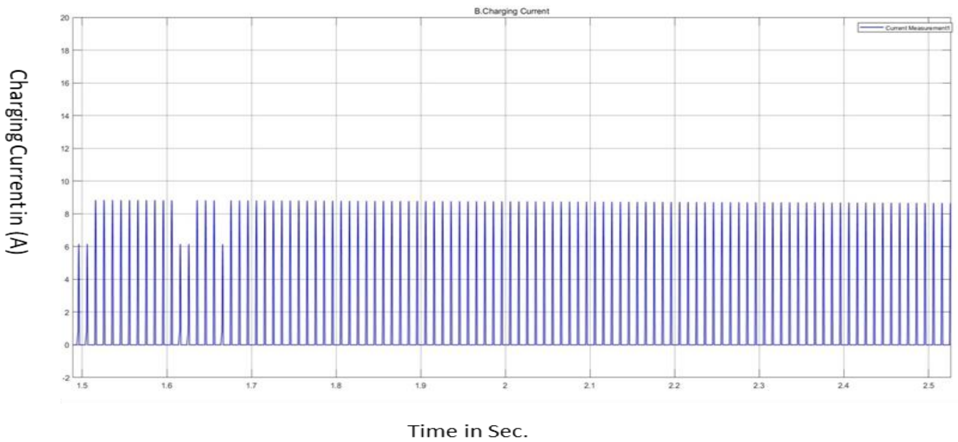

Figure 4.21. Battery charger current of simple UPS system without PFC.

We tested our design structure for different value of load, to see the response of the battery charging and the inverter. Firstly we run the module with full-load (62 Ohms), (Figure 4.22).

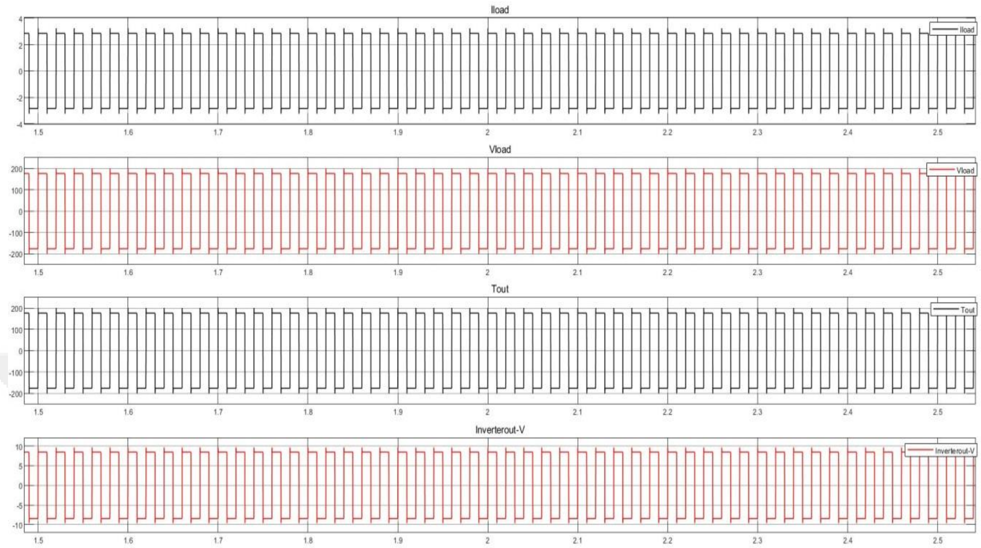

Figure 4.22. Output waveform of Simple UPS Full-load.

By changing the load to Half-load (100 Ohms) we output voltage coming down as in Figure 4.23, but the efficiency will be lower and the THD still very high.

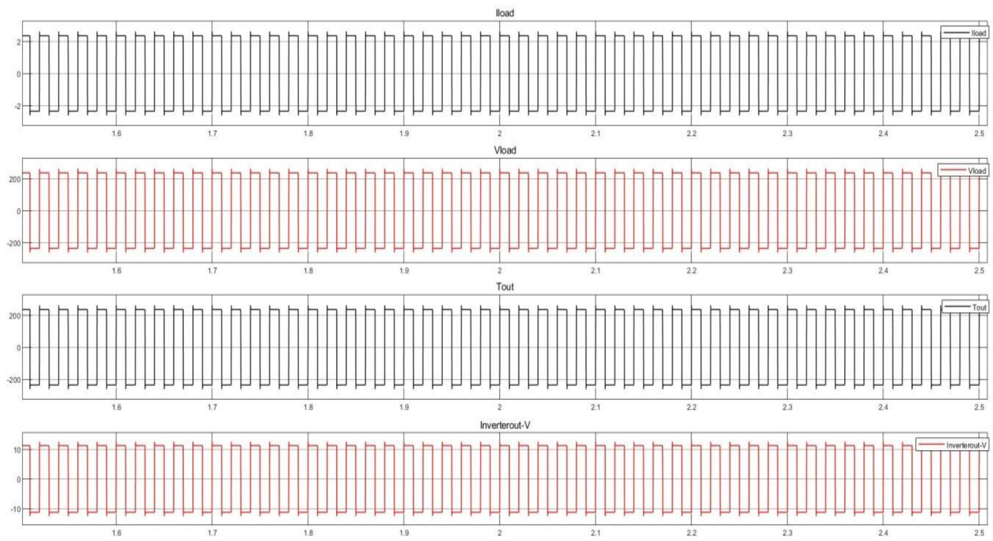

Figure 4.23. Output-waveform of Simple UPS Half-load.

In third case we put a quarter-load (200 Ohms), (Figure 4.24). We see the output-voltage will be less compare with full-load and the efficiency of the device will be less.

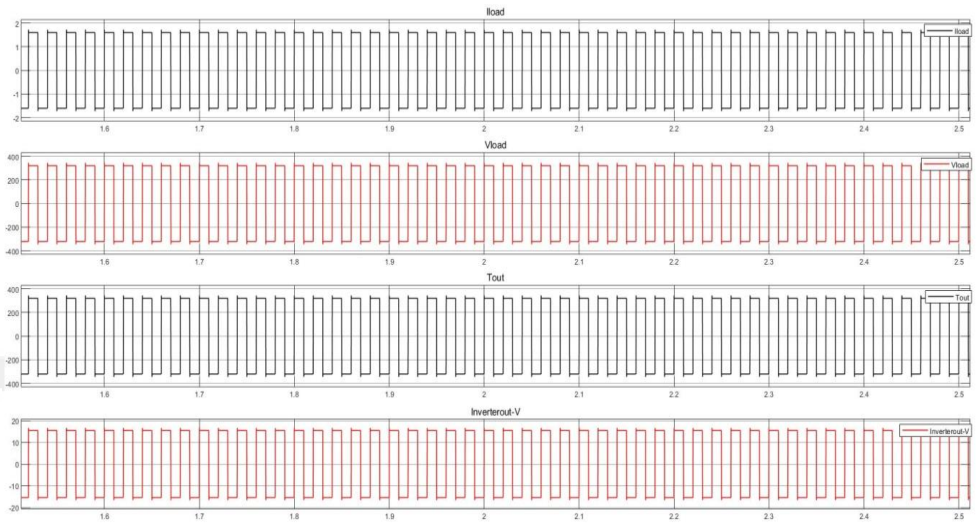

Figure 4.24. Output waveform of Simple UPS, Quarter-load.

In Table 4.3, we see the results of all cases by changing the load. The input power and THD stills the same because the load will be directly connected with AC main power source, just in case of main power interruption will be supplied from the inverter.

Table 4.3, Simple UPS system with load variation,

Simple UPS System	**Full-load 62 Ohms**	**Half-load 100 Ohms**	**Quarter-load 200 Ohms**
Input Line THD (%)	207	207	207
Output Load THD (%)	48.24	48.23	48.23
Input Power (VA)	1514	1514	1514
Output Power (VA)	812.7	893	838.3
Load Current (A)	2.8	2.3	1.6
Input Cos θ	0.9716	0.9716	0.9716
Output Cos θ	1	1	1

5. CONCLUSION AND DISCUSSION

To see the different between all three types of our design structures we should find the response of each one by load variation. Table 5.1, shows all three types of UPS in case of connected with Full-load. According to Santhosh and Shreeshayana, (2017), the using of a controlled boost converter to improve input PFC and THD is one of the best topologies to design an efficient UPS system as Off-line and On-line.

Table 5.1. Comparison between all three types of UPS Full-load,

UPS Systems (Full-load)	**Off-line**	**On-line**	**Simple**
Input Line THD (%)	4.3	2.5	207
Output Load THD (%)	4.58	3.8	48.24
Input Power (VA)	1695	3175	1514
Output Power (VA)	1348	1528	812.7
Load Current (A)	4.5	5	2.8
Input Cos θ	1	1	0.9716
Output Cos θ	1	1	1

In the Table 5.2, we see the results of all three types of UPS in case of Half-load.

Table 5.2. Comparison between all three types of UPS Half-load,

UPS Systems (Full-load)	**Off-line**	**On-line**	**Simple**
Input Line THD (%)	4.3	3.3	207
Output Load THD (%)	3.18	2.3	48.23
Input Power (VA)	1695	2361	1514
Output Power (VA)	972.5	1090	893
Load Current (A)	3	3.3	2.3
Input Cos θ	1	1	0.9716
Output Cos θ	1	1	1

And finally we put a quarter-load for all three types of UPS and we got the results as in Table 5.3.

Table 5.3. Comparison between all three types of UPS Quarter-load,

UPS Systems (Full-load)	Off-line	On-line	Simple
Input Line THD (%)	4.3	3.9	207
Output Load THD (%)	3.84	2.7	48.23
Input Power (VA)	1695	2089	1514
Output Power (VA)	560.4	679	838.3
Load Current (A)	1.6	1.85	1.6
Input Cos θ	1	1	0.9716
Output Cos θ	1	1	1

According to Pino and Sepúlveda (2012), the output waveform of Off-line UPS is sinusoidal by using APFC with controlled inverter to avoid creating a square or semi-sinusoidal waveform of the output voltage.

Most of commercial off-line UPS system have a pure power factor (Table 5.4), because passive power factor correction circuit with input or output LC filters could improve the power factor but never reaches nearly unity. Using active power factor needs additional circuits to improve the power factor and reducing the THD, and that will be costly. By connecting a critical load (or sensitive equipment) the input power factor and THD is important, therefore using an Online Uninterruptible Power Supply system with active PFC is necessary to protect the critical load from any abnormality of the AC main power source.

Table 5.4. Same available commercial Off-line UPS system in point of view power factor,

Brand	Model	Capacity VA/Watt	PF	Reference
SOLAHD	S3K1600	1600 / 1200	0.75	“www.solahd.com”
Schrack	USIPLUG60	600 / 360	0.6	“www.schrack.com”
Schrack	USIPLUG80	800 / 480	0.6	“www.schrack.com”
S-link	SL-UP1200	1200 / 720	0.6	“www.segment.com.tr”
Schneider	BVS10001GR	1000 / 600	0.6	“www.hepsiburada.com”
CPSY	Shangyu Electronic -S1000VA	1000 / 600	0.6	“www.globalsources.com”

According to reel marketing research we found that, there are a big difference between what we did and the available off-line UPS in the market in case of input PFC and THD, they have in general 0.6 inputs PFC and that make big losses.

As a final result we see Off-line and On-line UPS design structures with power factor correction circuit will correct the power factor and THD by Input and output of the circuits as it was required in the beginning. By a normal UPS like our simple design in the structure the power factor and THD will be affected by any kind of rectifier circuit and nonlinear load. The only challenge of such kind of UPS is the efficiency especially in case of On-line UPS, because all circuits are in operating state all the time.

Improving power factor is important for any device and the Utility too, because an electric device with a lower PF draws more than current an electric device with a higher than PF for the same useful energy transferred. Any equipment operates with DC voltage needs AC to DC rectifier, and this rectifier distorts the current drawn from the utility grid due current harmonics. Many applications required DC power supply and to convert that from AC power supply, a rectifier has to be used. This rectifier leads to lower power factor and high THD. Therefore the PF has to be improved and also reducing the input current harmonics is also required. A passive PFC could improve the PF for linear load, but never achieves more than 0.9. By using boost converter active PFC we achieved nearly unity of PF and reduced the input THD to less than 5% for off-line and On-line UPS as shown in our simulated modules results.

Using a boost converter in Average Current Mode Control (ACMC) with 2 PI controller provided a good result of PF for the circuits and we achieved nearly unity of PF for design topologies, also the input current Harmonics and output THD are minimized to an extent (less than 5% for both sides).

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APPENDIX1. Genişletilmiş Türkçe Özet (Extended Turkish Abstract)

ÖZET

KESİNTİSİZ GÜÇ KAYNAKLARININ GÜÇ KATSAYISININ DÜZELTMESİ

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Tez Danışmanı : Prof. Dr. Naci, GENÇ
Ekim 2020, 111 sayfa

Ana güç hattının bir kesintiye uğramasını önlemek için kesintisiz bir güç kaynağı (UPS) kullanılır. Günümüzde en kritik yükler (Cihazlar) ana güç kaynağından gelen tüm sorunlardan kaçınmak için çevrimiçi bir UPS sistemine bağlanmaktadır. Genellikle, kesintisiz güç kaynağı sistemi elektrik sistemi için yedek güç olarak kabul edilir, çünkü kritik yük uygulamalarında, ana güç kaynağı koşullarında bir anormalleşme olduğunda sürekli gücü korumak için her zaman UPS sistemine güvenilir.

Günümüzde hat akımı harmoniklerinin azaltılması veya güç faktörü düzeltmesi çok gereklidir ve bunu iyileştirmek için pasif güç faktörü düzeltmesi ve aktif güç faktörü düzeltmesi olmak üzere iki tür yöntem vardır. Çoğu ticari UPS sistemi, sistemin maliyetini düşürmek için hat LC filtreleri kullanarak pasif güç faktörü düzeltmesini kullanmıştır.

Bu tezin amacı, iki PI Kontrolcüsü tarafından denetlenen Ortalama Akım Modu Kontrolcüsü (ACMC) ve Yükselten dönüştürücülü ile beslenen Tam Köprü doğrultucusunun kullanıldığı UPS sisteminde, Toplam Harmonik Bozulmalarını (THD) minimum seviyeye çekilmesi ve güç faktörününün iyileştirmesidir. Bu tezde yaklaşık 800 VA'lık birbirinden farklı UPS sistemlerinin (PFC'siz basit UPS, aktif PFC'li Off-line UPS ve aktif PFC'li On-line UPS) aktif güç faktörünün (PFC) düzeltmesi için önerilen yöntemler tasarlanmakta ve karşılaştırılmaktadır.

Tasarım kolaylığı ve uygulanabilirliğinden dolayı tam köprü çift dönüşüm topolojisi seçildi ve benzetim çalışmaları Matlab-Simulink ortamında gerçekleştirildi.

Sonuç olarak, Giriş ve çıkış tarafındaki güç faktöründe neredeyse bir uyum elde edilir ve toplam harmonik bozulmalar yaklaşık %4'e düşmektedir.

Anahtar kelimeler: PI Kontrolcü, PFC, Off-Line, On-Line, UPS, THD.

1. GİRİŞ

Kesintisiz Güç Kaynağı (UPS), kritik yükleri AC ana güç kaynaklarındaki herhangi bir meydana gelen kesintiden veya arızadan koruyabilir. Kesintisiz güç tedarikine ihtiyaç duyan sistemler tipik elektrik yükü veya süreçlerin (Veri işlemleri için bilgisayarlar, otomatik üretim, yaşam destek cihazları, İletişim sistemleri, Tehlike izleme ve alarm sistemleri) sürekliliğini sağlar.

Normalde, UPS sisteminin ana güç sorunlarının sonuçlarından kaçınmak için iki işlevi vardır; birincisi ani yükselmeleri, frekans ve düşük voltaj dalgalanmalarını gidermek, güç faktörü düzeltmesi, ayrıca ana kaynağın harmoniklerin azaltılması, ikincisi ise geçici güç beslemesi sağlamaktır. Bu işlevleri yerine getirmek için, UPS sistemlerinde Ana güç kaynaklarının kesintileri sırasında kritik yüklere acil durum bekleme gücünü sürekli olarak sağlamak ve toplam sistemin doğruluğunu belirlemek için bir akü grubu bulunmaktadır.

Tüm UPS'lerin işlevselliği aynıdır, ancak kapasiteleri ve ebatları farklıdır. Yükün özellikleri, UPS'in boyutunu ve türünü belirler. Esas olarak güç kaynağı, akü grubunu şarj etmek için ana kaynak gücünü (50/60 Hz AC) temiz bir Doğru Akım (DC) gücüne dönüştüren ve ardından DC'den AC dönüştürücüye güç sağlamak için şarj cihazına enerji verilir. Evirici, kritik yük için kullanılabilir enerji olarak doğrultucudan veya Aküden gelen Doğru Akım gücünü (AC) voltajına dönüştürür.

Ana güç kaynağı kesintilerinde akü grubu, yüke sınırlı bir süre enerji sağlamak için eviriciye enerji sağlamak için birincil güç kaynağı olarak çalışır ve bu süre, cihazda tasarruf edilen güç miktarına bağlıdır. Akü sistemi veya başka bir deyişle akü sisteminin boyutuna ve kapasitesine bağlıdır. Bir UPS sistemi, enerji beslemesinin hiçbir zaman kesintiye uğramamasını sağlamalıdır.

Aslında, Şebeke gücü temiz değil. Şebeke güç tedarikinde dokuz önemli sorun vardır; (Güç Kesintisi; Güç Düşüşü; Güç Dalgalanması; Düşük voltaj; Aşırı voltaj; Elektrik Hattı Gürültüsü; Frekans Değişimi; Anahtarlama Geçici ve Harmonik Bozulma). Birçok ülkede yasalar gereği, kamu hizmetlerinin güç tedarikçisi, kritik yük için önemli sorunların artmasına kadar büyük ölçüde değişiklik gösterebilir. Acil Durum Jeneratörleri ve aşırı gerilim baskılayıcılar, elektrik kesintisi ve diğer rahatsızlıklardan kaynaklanan sorunları önlemek için yeterli değildir, çünkü sadece güç kesintisi durumunda başlatma ve güç sağlamak zaman alır ve kritik yükü güçten korumaya yardımcı olmaz. UPS sistemleri iki özel amaca hizmet eder. Yükü, şebeke gücündeki anormallikten korurlar ve jeneratörün çalıştırılması ile şebeke güç kesintisi arasında bir süre güç sağlarlar. Çevresel kirlenme, fosil yakıtların yetersizliği ve artan enerji talebi geleneksel güç sistemlerinin bazı sorunlarındandır. Bu problemler Rüzgar enerjisi, yakıt pili ve Güneş enerjisi gibi yenilenebilir enerji kaynaklarına yönelmeyi gerektirir. Sürdürülebilir enerji kaynağın bir çeşidi olan ve düşük çalışma maliyetiyle yüksek verimliliğe sahip olan Güneş enerjisi odak noktası olmuştur.

Farklı arayüzlere sahip şebeke bağlantılı birçok enerji sistemi vardır fakat şebeke bağlantılı Güneş enerjisi sisteminde Güneş ışığı, yarı iletken güneş hücreleri vasıtasıyla DA güce dönüştürülür. Sonrasında DA güç DA-AA çevirici kullanılarak AA güce çevrilir ve trafoda yükseltilerek şebekeye verilir. Sistemin dinamik davranışı, çeviricinin özelliğine ve kontrolüne, FV panellere, radyasyona, sıcaklığa ve tasarım ve kullanım yöntemlerine bağlıdır.

FV sistemlerini oluşturmak için genellikle iki yöntem vardır. Birincisi yüke doğrudan bağlı olan çatılarda veya zeminde kurulu FV sistemidir. İkincisi ise özellikle uzak mesafelere kurulan ve geniş zemin gerektiren şebekeye bağlı FV sistemidir. Güneş enerjisi pazarı özellikle şebekeye bağlı FV sistemlerinde son yirmi yıldır hızlı bir artış göstermiştir ve gelecekte de bu artışın devam etmesi öngörülmektedir. Son on yılda FV üretimi geleneksel yöntemlere nazaran %40 oranında artış göstermiştir. FV sistemlerin güç sistemiyle birleşimi belli teknik etkilere neden olmuştur. Güç kalitesi, güç sisteminin çalıştırılması ve kontrolü ve sistemin kararlılığı bu teknik etkilerden bazılarıdır.

2. MATERYAL VE YÖNTEM

Genel olarak "Kesintisiz güç" veya kesintisiz güç kaynağı, bir organizasyondaki herhangi bir operatörün ana sorunu ve sorumluluğudur, çünkü kesintiye uğrayan herhangi bir güç, paraya veya bazen özellikle hastanelerde insanların hayatına mal olabilir. Organizasyondaki hassas ekipman türleri, tüm kritik yüklerin sürekli olarak bir güç beslenmesi gerekir ve güç kalitesi de önemlidir çünkü bu tür cihazlar herhangi bir sinüzoidal olmayan giriş akımına duyarlıdır. Başka bir tarafta, PF ve giriş akımı THD, güç dağıtım sistemi ve hat şebekesi üzerinde bir etkiye sahiptir.

Tüm güç kaynağı sorunlarından kaçınmak için, ana güç kaynağı arızasının meydana gelmesi, maliyet, boyut, bakım, yükün türü ve boyutu, acil durumun normalleşme süresi ve gibi tüm kritik parametreler dikkate alınmalı. UPS sisteminin birçok topolojisi vardır ve UPS topolojisini kategorize etmek zordur çünkü yapılarına; tasarım mimarisine, çalışmasına, konfigürasyonuna, boyutuna, sinüzoidal çıkış voltajına / akımına, güvenilirliğine, verimliliğine, düşük THD, elektriksel izolasyon, güç faktörü ve yük özellikleri göre değişmektedir. Aslında tüm bu özellikleri sağlayan tek bir tasarım yoktur.

Genel olarak basitleştirmek için öncelikle UPS sistemlerini yapılarına göre (statik; döner; ve diğer ikisinin kombinasyonu olan hibrit), ikincil statik tipler ise tek dönüşüm, çift dönüşüm ve çoklu dönüştürme gibi dönüşüme bağlıdır. Diğer taraftan, statik UPS sistemi çevrimdışı, çevrimiçi ve hat etkileşimli (seri-paralel yapılandırmalar) olarak sınıflandırılır. Ayrıca tüm bu tipler için tek fazlı ve üç fazlı türleri vardır.

Veri merkezi gibi bazı kuruluşlar için güç kaynağını garantilemek için sistemi kümelemek çok önemlidir, UPS topolojilerinin "N topolojisi" olarak adlandırılan başka bir kategorisi vardır ve yapısal olarak ayrıca merkezi tasarım topolojileri de vardır.

Tüm UPS sistemi türleri, ana güç kesildiğinde yüke sağlanabilecek yedek güç sağlamak için akü grubu gibi bir enerji deposu kullanır. Diğer taraftan volan ve hidrojen hücresi gibi acil durum enerji depolamanın yakın gelecekte ortak bir uygulamada kullanılması olası değildir. Ayrıca, tüm UPS türleri, kritik yükün AC ana gücüne bağlanması için bir yol sağlayan bir "baypas" sistemi içerir.

Son olarak, UPS sistemini, kritik bir yükün veya hassas ekipmanın sürekli olarak çalışmasını ve gerekli güç koşullarını kesintisiz olarak sağlamak için bir çözüm olarak değerlendirebiliriz. Burada her bir UPS sistemi türünü ve nasıl çalıştığını, her birinin avantaj ve dezavantajlarını gösterilmiştir.

3. BULGULAR VE TARTIŞMA

Bu tez çalışmasında, doğrultucu, yükseltici dönüştürücü, İzole düşüren dönüştürücü, Akü şarj cihazı, kontrollü İnvertör, Yükseltici Transformatör, çıkış LC filtresi ve son olarak bir baypas hattı içeren tek dönüşümlü topolojiye sahip Off-line UPS tasarlanmaktadır. Çevrimiçi UPS'in benzer öğelere ihtiyacı olacaktır; ancak yöntem çift dönüşüm topolojisi olacaktır. Hem çevrimdışı hem de çevrimiçi topolojilerde, "ortalama akım modu kontrol" yöntemini kullanarak aktif bir PFC devresine sahip olmak için her dönüştürücü için bir kontrolör ekliyoruz. Üçüncü UPS sistemi, sonuçları diğer ikisiyle karşılaştırmak ve güç faktörü düzeltme devrelerini eklemenin etkilerini görmek için herhangi bir Güç faktörü düzeltmesi olmadan çok basit olacaktır.

Çevrimdışı, Çevrimiçi ve basit UPS sistemleri tasarımımızın her bir bölümünü açıklanmakta. Daha önce de belirtildiği gibi, neredeyse birim güç faktörünü elde etmek ve giriş toplam distorsiyon harmoniklerini % 5'in altına düşürmek için hem giriş için hem de sistem çıkışı (yük) için aktif bir PFC kullanılması gerekiyor. Burada, PF girişini doğru yerleştirmek ve dönüştürücü Çıkış Voltajını sabitlemek için kontrollü bir yükseltici dönüştürücü topolojisi ve ACC yöntemi kullanılmaktadır. Yükseltici dönüştürücü, gerilimi 311 DC V ‘dan (Tam köprü diyot doğrultucu ile doğrultulduktan sonra) 400 DC volta yükseltir ve sabitler. Tasarlanan sistemin DC Barası 24 Volt olacak şekilde tasarlandı ve böylece yaklaşık 800 VA'lık bir yükü besleyebilecek 24 Volt'luk (2x12 Volt akülerden oluşur) akü grubu şarj edilmektedir.

Akülerin şarj edilebilmesi için 400 DC V'yi 24 DC V'a düşürmenin başka bir tarafı, bir düşüren dönüştürücü gibi bir düşürücüye ihtiyaç var, ancak bu voltaj düşüş oranı (24/400 =% 6) çok fazla, bu nedenle akü grubu ve DC bara ihtiyaç duydukça voltajı düşürmek ve sabitlemek için yüksek frekans transformatörlü bir İzole düşürücü dönüştürücü kullanılmaktadır. Aküyü şarj etmek için şarj voltajını DC bara voltajından biraz daha yüksek olmalı, bu nedenden dolayı bu izole düşüren dönüştürücünün çıkış voltajı 26.5V olacak şekilde ayarlandı.

Herhangi bir UPS sisteminin tasarım yapısının ikinci kısmı evirici tarafıdır. Aküden 24 DC volt dönüştürmek için bir invertöre ihtiyaç var. Burada 24 AC voltluk sinüzoidal dalga formu elde etmek için kontrollü bir tam dalga dönüştürücü kullanılmaktadır. Bu gerilimi artırmak için yükü beslemek için çıkış LC filtreli bir transformatör eklenmektedir.

Off-line ve On-line UPS sisteminin her ikisinde de bileşenler aynıdır, sadece Bypass hattının bağlantısı ve inverterin çalışma süresi farklıdır çünkü Off line kesintisiz güç kaynağı sisteminde inverter sadece AC ana güç kesintisinde çalışır, ancak Çevrimiçi kesintisiz güç kaynağı sistemi durumunda, inverter her zaman çalışır durumda olacak ve yükü invertör aracılığıyla sağlayacak ve yük ana kaynaktan izole edilecektir.

Üçüncü UPS tasarım yapısında, basit UPS için, PFC için ek bir devre içermeyen bir yükselten dönüştürücü mevcuttur.

4. SONUÇ

Bu tez çalışmasında; giriş / çıkış güç faktörünün iyileştirilmesi ve Toplam Harmonik bozulmalarını azaltması hedeflenmektedir. Matlab-Simulink yazılım programı kullanılarak her üç tip UPS sistemi için gerekli tasarımlar yapıldı ve bu tasarımlar çalıştırılıp THD yüzdeleri ile giriş dalga formu ve güç faktörü gözlemlendi ve gerekli bilgiler kaydedildi. Önerilen üç UPS için alınan değerler birbirleriyle ve piyasada mevcut bazı UPS sistemleriyle karşılaştırılarak, detaylı bir şekilde analizler yapıldı.

Giriş güç faktörünü iyileştirilen ve THD'si düşürülen UPS'in kayıplarında azalma görüldü; çünkü iyileştirilmeyen güç faktörü ve yüksek THD oranı daha fazla kayıp anlamına gelir. Aktif PFC kullanılan UPS'in verimliliği, özellikle çevrimiçi UPS sistemlerinde daha düşük olacağı doğrudur, çünkü AC ana gücü mevcut olduğunda da tüm devreler her zaman çalışır durumda olacaktır. Pasif PFC kullanarak, en yüksek PF oranı 0,9'a ulaşır ve bu giriş gücünün yaklaşık% 10'unun kayıp olarak gittiği anlamına gelir. Bu enerji miktarı, özellikle tam yük sağlanması durumunda, UPS sistemini çalıştırmak için kullanılan enerji miktarı ile yaklaşık olarak aynıdır. Ancak daha düşük verimlilik sorunu, UPS sisteminin yarım yük sağlaması ve cihazdaki güç kayıplarının nispeten daha yüksek olması ve güç faktörü ve THD'nin daha az etkili olmasıdır.

Güç faktörünün iyileştirilmesi, herhangi bir cihaz ve tesis için de önemlidir, çünkü daha düşük bir PF'ye sahip bir elektrikli cihaz, daha yüksek PF'ye sahip başka bir elektrikli cihazdan daha fazla akım çekerek faydalı enerjiyi sağlayabilmektedir. DC voltajı ile çalışan herhangi bir ekipman AC'den DC'ye doğrultucuya ihtiyaç duyar ve bu doğrultucu, akım harmonikleri nedeniyle şebekeden çekilen akımı bozar. Birçok uygulama DC güç kaynağına ihtiyaç vardır ve bu, AC güç kaynağına doğrultucu eklenerek gerçekleştrilmektedir. Bu doğrultucu, daha düşük güç faktörüne ve yüksek THD'ye yol açar. Bu nedenle, PF'nin iyileştirilmesi gerekir ve ayrıca giriş akımı harmoniklerinin azaltılması da gereklidir. Pasif bir PFC, doğrusal yük için PF'yi iyileştirebilir, ancak hiçbir zaman 0,9'dan fazlasını başaramaz. Yükselten dönüştürücü aktif PFC kullanarak, yapılan benzetim çalışmalarından elde edilen sonuçlarda gösterildiği gibi, PF neredeyse bir uyum elde edildi ve giriş THD'sini çevrimdışı ve Çevrimiçi UPS için% 5'in altına düşürüldü.

Ortalama Akım Modu Kontrolünde (ACMC) 2 PI denetleyicili bir yükseltici dönüştürücü kullanmak, devreler için iyi bir PF sonucu sağladı ve tasarım topolojileri için neredeyse PF uyumu elde edidi, ayrıca giriş akımı Harmonikleri ve çıkış THD’si bir dereceye kadar en aza indirildi (her iki taraf için% 5'ten az).

CIRRICULUM VITAE

Sarko O. Hama was born in Sulaimaniya, Iraq, in 1969. He received his B.Sc. degree in 1991 from Mosul University at Electrical and Electronics Engineering Department. He was employed at MOE-KRG as an expert engineer 2007-2016.

APPENDIX2. Originality Report

UNIVERSITY OF VAN YUZUNCU YIL
THE ISTITUTE OF NATURAL AND APPLIED SCIENCES
THESIS ORIGINALITY REPORT

Date: 08/09/2020

Thesis Title: Power Factor Correction of Uninterrupted Power Supply Systems

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Sincerely yours,

Sarko Othman HAMA
08.09.2020

Name and Surname: Sarko Othman HAMA

Student ID#:18910001077

Science: Institute of Natural and Applied

Program: Electric **a**nd Electronic Engineering

Statute: M. Sc. ☐ Ph.D. ☐

APPROVAL OF SUPERVISOR
SUITABLE

Prof. Dr. Naci GENÇ

APPROVAL OF THE INSTITUTE
SUITABLE

(Title, Name-Surname, Signature)