M.Tech (Power Electronics and Systems) Anupriya 2024

CURRENT CONTROL FRONT END AC-DC CONVERTER FOR ON-BOARD EV CHARGER UTILISING SECOND HARMONIC COMPENSATION

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In

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Submitted by

ANUPRIYA

(2K22/PES/03)

Under the supervision of

Prof. VISHAL VERMA

(Electrical Engineering Department, DTU)

DEPARTMENT OF ELECTRICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

MAY 2024

DEPARTMENT OF ELECTRICAL ENGINEERIN

GDELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, ANUPRIYA , Roll No. 2K22/PES/03 student of MTech (Power Electronic and Systems), hereby declare that the project Dissertation titled "**Current Control Front End AC-DC Converter for On-Board Ev charger utilising Second Harmonic Compensation"** which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in the partial fulfillment of the requirement for the award of degree of Masters of Technology, is original and is not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, fellowship or other similar title or recognition.

Place: Delhi ANUPRIYA

Date: 31st May 2024

DEPARTMENT OF ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project Dissertation titled "**Current Control Front End AC-DC Converter for On-Board Ev charger utilizing Second Harmonic Compensation"** which is submitted by ANUPRIYA (2K22/PES/03), Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date: 31st MAY 2024

Prof. VISHAL VERMA

(SUPERVISOR)

Department of Electrical Engineering

ACKNOWLEDGEMENT

It is a matter of great pleasure for me to present my dissertation report on "**Current Control Front End AC-DC Converter for On-Board Ev charger utilizing Second Harmonic Compensation**"**.** First and foremost, I am grateful to my guide Prof. Vishal Verma, Department of Electrical Engineering for his expert guidance and continuous encouragement during all stages of my thesis, in form of valuable information and research papers at appropriate time brought life in this thesis That I have the chance to work with him makes me feel privileged. This thesis now has a direction thanks to his practical approach to the engineering issues. It was thought-provoking not only to grasp the topic but also to analyze the conclusions from the graphs. Along with my managers, I also want to thank the following: To my siblings Ashutosh Pankaj and Anisha, whose unwavering love for my job and life in general gave me the strength to continue going; to my parents Narendra Kumar and Kavita Devi, for their unwavering support and prayers; without them, I would not have reached this level of my life. In addition, I would want to express my gratitude to Mr. Sushant Singh, my senior, for being there for me at both the high and low points of my adventure. At last, I want to express my gratitude to everyone who helped me, either directly or indirectly, to finish this project.

Date: 31st May 2024

Place: DELHI ANUPRIYA

ABSTRACT

AC-DC conversion mandatorily leave the second-order harmonic footprints in the currents on the DC bus which has large amount of ripple voltages calling for implementation of large DC-capacitance, which not only results in poor device power density but also alter the characteristics of the converter to a voltage source not suitable for eV charging applications which demands for current converters. The current harmonic pollution poses a huge threat while charging of batteries in terms of stability, safety, and efficient operation even executing as front-end stage for the cascaded buck type converter. This paper presents a new technique to extract the second order harmonics component from the current at the rectifier's output using low computation and easily implementable different bandwidth moving average low pass filters. The second harmonic current compensator (SHCC) using single phase self-supporting voltage source inverter eliminates the second harmonic currents (SHC) in the output side without influencing the PFC configuration on the AC side, thus drastically reducing the size of the capacitance of the filter. The analysis of filtering technique and configuration of the compensator along with control of PFC is dealt in detail. The simulation results demonstrate the ability of the proposed compensator works well with PFC AC-DC converter to offer current based control suitable for battery charging without large 2nd harmonic ripples. The simulation and analysis is performed by keeping the devices and parameters in their ideal nature.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

A paradigm shift is witnessed in the domain of mobility as a result of the electrification of transportation is rapidly growing in the world. Electric vehicles, or battery-controlled vehicles, offer fewer pollutants, greater utilization, more efficiency, and higher execution levels than traditional IC-based vehicles, making them a choice for future electrification transportation. Consequently, there is a rising demand for batteries that are easy to plug in and out, lightweight, and portable.

When the PWM rectifier's dc output is linked to batteries, most of the dc ripple current passes into the batteries due to the low impedance of the batteries compared to the prior-art circuit. Particularly the ripple components due to low frequencies harmonics are harmful and causes heating and a subsequent rise in temperature, leading to degradation of battery.

Many academics have focused on the problem of reducing second-order harmonics in single-phase PFC converters because of its significance presence in the charging current. Various control techniques and circuit topologies have been put forth in the literature as second stage to minimize the problems of lower order harmonics. A reduction in the ripple can be achieved through the utilization of large DC-bus capacitor banks, but its presence changes the response of the circuit to a voltage source contradicting the current based charging approach. Because of these the converter's total size, weight, and price are all increased by this method the use of LC trap filters

are explored but due to its presence on DC side the capacitance has to withstand large voltage Alternatively, employment of an active filter alleviates the second order and and the lower order harmonic ripples can be more effectively and efficiently moved by adding additional controlling circuitry [5]. This method manages to reduce second-order harmonic ripple without sacrificing size, weight, or cost, but it comes at slightly higher cost and more complicated system.

The topic of making changes has been presented in a lot of studies. In order to separate the DC component and ripples, most transformations use different orthogonal voltage generating methods. In contrast to the current techniques, a PLL structure based on the second order Generalized Integrator (SOGI) can be used to create an orthogonal system in single-phase systems [6]. Stationary frame references with DC-offset, harmonics, and sub-harmonic rejection capabilities are generated using a second order generalized integrator-frequency locked loop (SOGI-FLL) that is designed with a pre-filter drawn upon AC side . Frequency dependence, excessive complexity, nonlinearity, and inadequate or nonexistent filtering are some of the drawbacks of all these approaches. The system's slowness is caused by the SOGI-based orthogonal voltage generating mechanism. Operating in constant current control mode with a single stage boost rectifier, this study suggests a new method based on moving average Low Pass Filters [7]-[9] acting on the dc side, that improves system reaction time and efficiency. The overall DC-bus voltage is then corrected by using feedback loops to eliminate the second-order harmonic components.

1.2 BATTERY CHARGER TYPES

A wide range of models and charging capacities are available for plug-in electric vehicle (PEV) battery chargers, meeting the diverse needs of electric vehicle drivers. Typically, Level one chargers are designed for usage in the home along with can be hooked up to a regular electrical outlet. Even though the first-level chargers are among the slowest, they make a good option for overnight charging, so your car will be ready to go the next day. Many homes, businesses, and public charging stations have Level two chargers installed to speed up the charging process. A specialized charging station is required for these chargers, which may be charged charging far faster than Level one chargers while offering greater power levels.

Thanks to innovations like intelligent connection, battery charger technology has progressed to the point where plug-in electric vehicle (PEV) owners can control and monitor their charging from anywhere using their smartphones. In order to optimize energy efficiency and reduce costs, several chargers are equipped with advanced functionalities such as load control. This allows customers to arrange charging sessions during periods of low demand, known as off-peak hours.

For plug-in electric vehicle (PEV) adoption to increase and range anxiety to decrease, there must be a widespread and easily accessible network of battery charges. Businesses, governments, and individuals can all do their part to make transportation a greener, more sustainable future by investing in charging infrastructure. To ensure that plug-in electric vehicle (PEV) owners have a positive charging experience and to support the further growth of electric car adoption, it is crucial to invest in the network for charging and for stakeholders to work together. Battery chargers for PHEVs are catalysts for the electric mobility revolution, not just a simple means of charging batteries. By efficiently charging plugin electric motor vehicles, these chargers contribute to cleaner, healthier, and more sustainable futures by promoting sustainable mobility behaviors and reducing emissions.

1.2.1 BATTERY CHARGING FUNDAMENTALS

Figure 1.1 shows the similar circuit model, a model to represent lithium-ion battery

(Li-Ion). This model aims to simulate the operation of a lithium-ion battery under various conditions using several circuit components. Down below, you can see a streamlined illustration of the electrical principle:

Open-Circuit Voltage (Voc) it is the battery voltage when no current is passing through the battery, this is its voltage. As the battery's state of charge (SoC) changes, this variable—typically measured or calibrated—is adjusted. Battery internal resistance is a measure of the impedance to current flow. It includes a number of potential resistance sources, including as the electrodes, the electrolyte, and the contact. Energy is lost when voltage drops due to internal resistance an energy source. Within this model's internal resistance component, ohmic resistance (Ro) and polarization resistance (RTH) converge. The capacity of a battery to store and discharge electrical charge is represented by its capacitance, which stands for CTH. The operational voltage of the battery is denoted by "V_B" here.

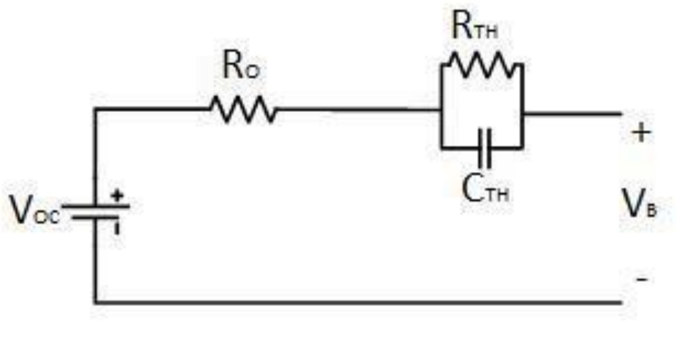


Figure 1.1: A Li-Ion Battery's Electrical Equivalent Model

Figure 1.2 illustrates the distinct charging characteristics of a lithium-ion battery. The

CC/CV mode, short for constant current/constant voltage, is the most widely used approach for charging Li-ion batteries. Figure 1.2 illustrates the process of recharging a specific lithium-ion cell to a designated nominal voltage.

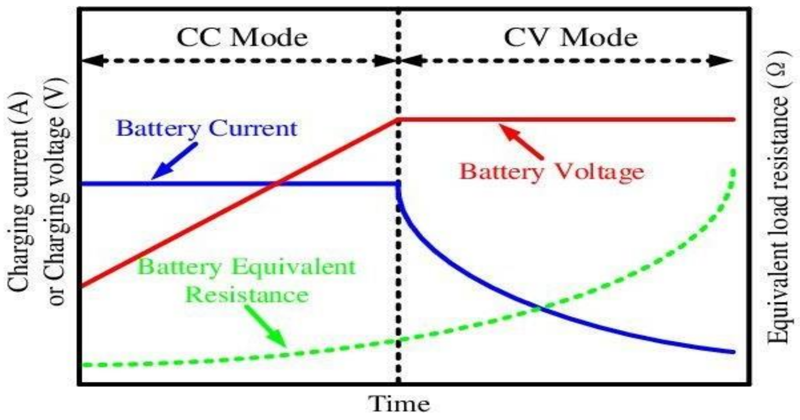


fig 1.2 : Li-ion cell charging

According to [5], there are four separate steps to the charging process. As the charging process begins and ends, so does the charging procedure. A discharged cell has a voltage lower than its nominal rating. Starting with a 100% state of charge (SoC), the battery is charged using the current that remains constant until it hits the inflection point, at which its voltage must be at its maximum. Subsequently, proceed to charge the battery using a constant voltage mode until the current diminishes to a level that is considered safe. Electric vehicles (EVs) rely on battery packs to store high-voltage direct current (DC) energy, which powers the electric drive trains. The power that most charging stations and the electrical grid use, however, is alternating current, or AC. To overcome this shortcoming, electric vehicles utilize an onboard charger or rectifier, which is also called an AC-DC converter, to transform the incoming AC power into DC power for charging the batteries. To facilitate safe and efficient power transmission to the vehicle's battery, the AC-DC converter transforms the erratic AC power source into a constant DC output.

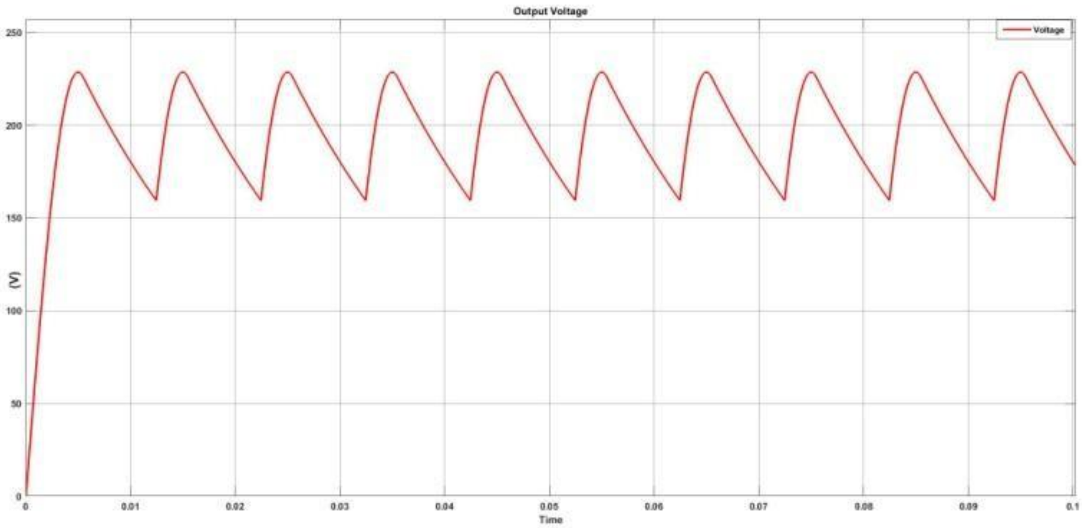
The main purposes of the converter are the rectification and conversion operations. Diodes enable positive half-cycles but block negative ones, resulting in a current flow in just one direction, converting the alternating current (AC) input from the grid to a pulsed direct current (DC) waveform during rectification. The result is a DC voltage somewhere in the center of the voltage spectrum. To convert it into a usable form for

charging an electric vehicle's battery, this intermediate DC voltage is fine-tuned.
A DC-DC converter and other power electronics circuits accomplish this by controlling the voltage to charge the batteries in an efficient and steady manner.

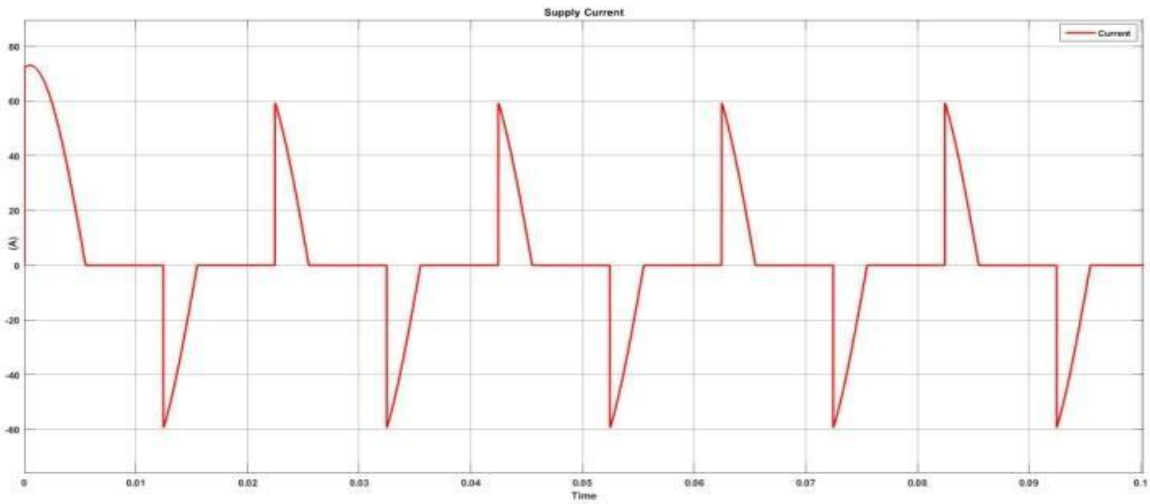
For the purpose of controlling power flow, monitoring charging progress, and ensuring safety, the AC-DC converter employs complex control algorithms. It works in tandem with the car's BMS to safeguard the battery from hazards like overcurrent and overvoltage, as well as enhance charging efficiency. Instead of needing extra DC-DC converters, the AC-DC converter can charge the battery and power the vehicle's auxiliary systems, supplying onboard electronics and accessories with low-voltage DC power.
Enhancing efficiency and implementing power factor correction (PFC) are two of the most important design considerations for an AC-DC converter. An increase in efficiency lessens power consumption and improves charging effectiveness by minimizing energy loss during conversion. By lowering harmonic distortion, reactive power consumption, and grid power resource use, PFC approaches improve electricity quality.
The AC-DC converter plays a crucial role in charging electric vehicles' batteries by transforming grid AC power into the DC power required.
It also helps with system integration, safe and dependable charging, and efficient power conversion, all of which contribute to the widespread use of EVs.
The diode bridge rectifier (DBR) with a filter capacitor is a common topology for rectifiers, although phase-controlled rectifiers are more commonly used for applications with high ratings and three phases. However, due to source inductance, classical rectifiers alter the voltage at the PCC and add harmonic components to the line current. As a result of this distortion, total harmonic distortion (THD) might rise and power factor can fall, leading to inefficiencies and potential issues with the power system.

1.3 DIODE BRIDGE RECTIFIER WITH CAPACITOR FILTERS.

It is necessary to incorporate filters into the fundamental DBR circuit in order to reduce the voltage swings that occur at the output and to improve the output average. The capacitive filter is another type of filter that is frequently utilized. In general, the concentration of the filter capacitor is determined by the amount of ripple in the output voltage that is allowed to be present.



Fig(a)



Fig(b)

Figure 1.4 - (a) Out voltage without C (b) Supply Current with C (200µF)

Figure 1.4(a) shows that there is a peak-to-peak ripple of 60 distinct voltages in the voltage. To further decrease ripple, it is possible to increase the value of the filter capacitor.

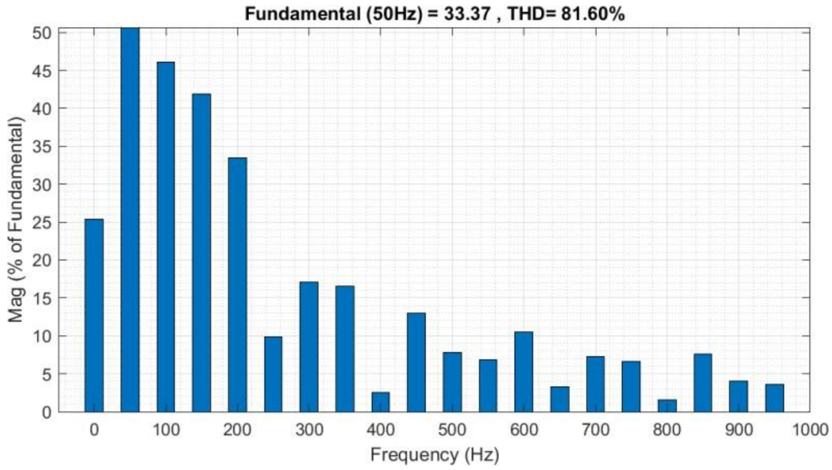


Figure 1.5 : FFT of input current

The current has a discontinuous character because one leg of the diodes is non-conductive for half of the supply cycle. Increases in capacitance cause diode conduction times to decrease, leading to greater peak input currents and total harmonic distortions (THDs).

Following this, the section that follows will provide an explanation of the mechanisms that are responsible for this transitory current behavior. It is possible that the sharp, high-amplitude bursts of current pulled from the supply are responsible for this large rise in total harmonic distortion (THD), which in turn causes severe harmonic distortion in the power system.

This is the defining characteristic of the input current. When the capacitance of a diode is increased, the conduction period of the diode reduces. This leads to a rise in the peak of the current coming into the device as well as an increase in the total harmonic distortion (THD). The subsequent section will provide an explanation of the underlying rationale for this transitory present behavior.

Figure 2.3(b) shows the input current and capacitor voltage (VC) in steady state. These diodes are reversely biased to prevent current from flowing into the converter when the input voltage is lower than the capacitor voltage. During this interval, the capacitor discharges to supply the load. Capacitors pull current from the supply when the input voltage is higher than their voltage, which causes the diodes to become forward biased.

1.4 HARMONIC STANDARDS

The current oscillations are defined by the ratio of the load current to the short circuit current, in accordance with the IEEE 519 - 2014 standard. Another way to look at it is as the percentage of the load kVA to the short circuit kVA at the location of common connection (PCC).

Table 1: Recommended Limits of voltage distortion and THD Levels.

BUS voltage at point of common coupling (PCC)	**Voltage Distortion (Industrial)**	**THD%**
V< 1kV	5	8
1kV < V < 69 kV	3	5
69kV < V < 161kV	1.5	2.5
161kV < V	1	1.5

A total harmonic distortion (THD) of 2.0% or more can be observed in high-voltage systems that use an HVDC termination. But as it travels across the network, this terminal's effect tends to fade, which could have an effect on other users who are linked in the foreseeable future.

1.5 EFFECTS OF CURRENT HARMONICS

Specific harmonic magnitude and phase values are anticipated from every non-linear demand in the form of a harmonic pattern. One way to quantify the number of harmonics in a given waveform is to look at the total current harmonic distortion (THD).

$$THDi,\% = \frac{\sqrt{\sum_{h=2}^{H} I_h^{\,2}}}{I_1} \cdot 100\% \qquad (1)$$

when H is the highest number of harmonics observed, Ih is the root-mean-square (RMS) value of the present's h-th harmonics component, and I1 is the root-mean-square (RMS) value of the mains frequency current component. Similarly, we can find the total harmonious distortion voltage (THDv) by substituting the voltage values for the current values in (1). A non-linear load is produced by power electronics converters, which handle charging as well as convert DC to AC, and by electric vehicle batteries, which need DC to charge. The charger's circuit architecture, which connects the electric car to the alternating current network, is closely related to the harmonics that come with imposing the motor.

Power factor correction (PFC) and current waveform shaping are two examples of the more network-friendly characteristics that have been incorporated into the circuits and management schemes because of the rapid evolution of these components. Detailed information regarding the development of the rectifiers' topologies, the waveforms associated with them, and the levels of the current harmonics has been presented in. The authors have relied on genuine measurements of several chargers, presenting actual waveforms that offer valuable information on the various conceivable topologies of chargers using these observations. In 1993, measurements of the first chargers indicated the usage of uncontrolled or low-control rectifiers, which revealed an average total harmonic distortion (THD) of fifty percent. EVs that were evaluated in 1995 presented near-sinusoidal current waveforms and THD levels that were lower than 7.5%, in contrast to the measurements of commercially available electric vehicles in 1994, which showed an average THD of 20%.

Chargers that have a high total harmonic distortion (THD) belong to an older topology and are not likely to be present in newer automobiles. A more recent analysis, which was presented in for various controlled battery charger front ends utilizing contemporary power semiconductors, demonstrates that there is a wide range of topologies that offer THD that is well below 5% with loads ranging from fifty percent to one hundred percent of the rated power. The levels of harmonics would continue to be lower than the constraints imposed by the regulations that are applicable. It is important to note that the power factor is currently more than 0.99. On the other hand, it appears that there is a little correlation between the input voltage levels and the higher harmonic levels. When the charger input voltage is increased, the lower harmonics (below 13th) are at a little higher level. On the other hand, when the mains voltage is decreased, the higher harmonics (above 15th) exhibit higher values.

In the most recent practical measurements of commercial electric vehicles, a total harmonic distortion (THD) of 11.6% was reported. Specifically, the standard limitations of the harmonic emissions have been determined and presented in reference number 20. Taking into consideration the restrictions given in IEC 61000-3-4 for particular harmonic emission levels, the maximum THDi that would be allowed for a charger would be 17.3%. When it comes to comparing just THDi, contemporary electric vehicles might easily fit under the standard restrictions. Note that regardless of the THDi value, the levels of the various harmonics may still exceed the limitations. This is something that must be taken into consideration. These levels are not something that the THDi indicates.

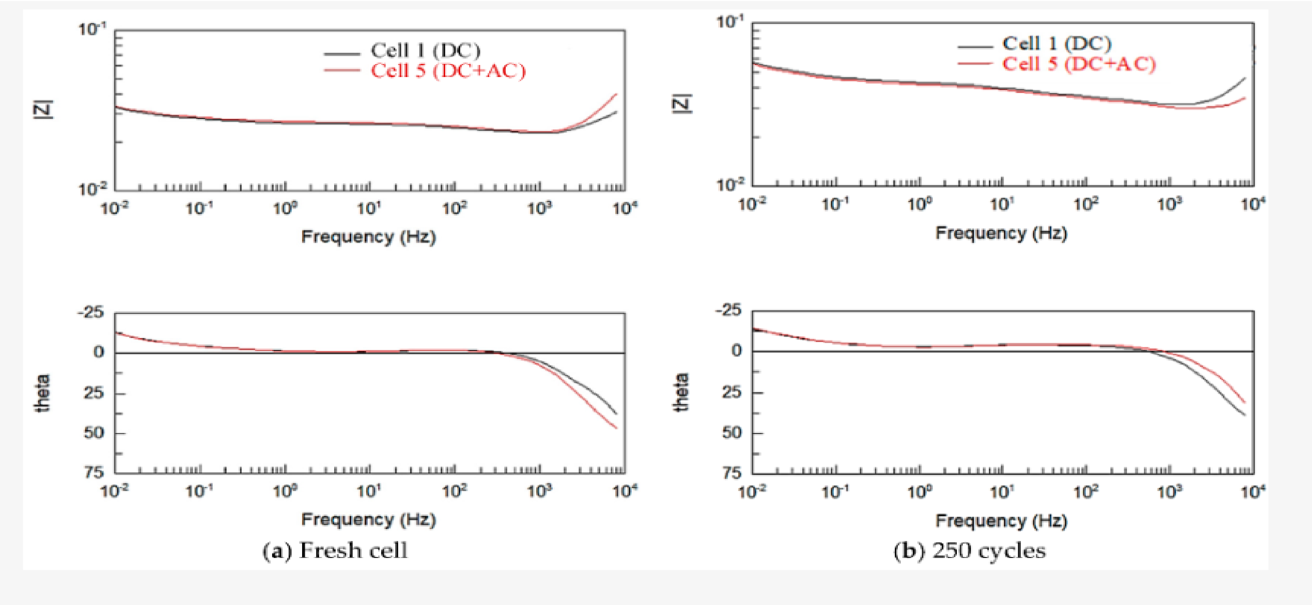


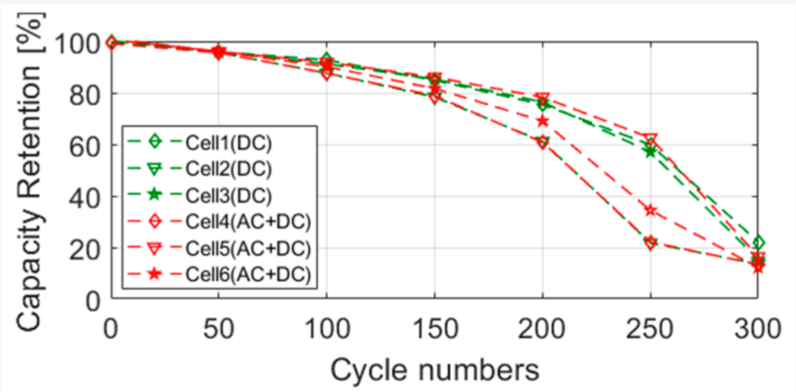
Fig 1.6 . Bode plot shows impedance vs. frequency and phase vs. frequency for cells 1 (**black**) and 5 (**red**) at 80% SOC, for (**a**) fresh cells, and (**b**) after 250 cycles were performed.

Harmonics that are present during the process of charging lithium-ion batteries in electric vehicles can have a number of negative impacts, the majority of which are caused by the deformation of the electrical waveforms. With the introduction of harmonics into the charging process, the AC-DC conversion becomes less effective owing to the presence of non-sinusoidal waveforms. This results in greater power loss in the form of heat, which in turn leads to increased power consumption. As a result of this heat generation, not only does the charging system's overall efficiency decrease, but it also places additional thermal stress on the power electronics as well as the battery cells themselves.

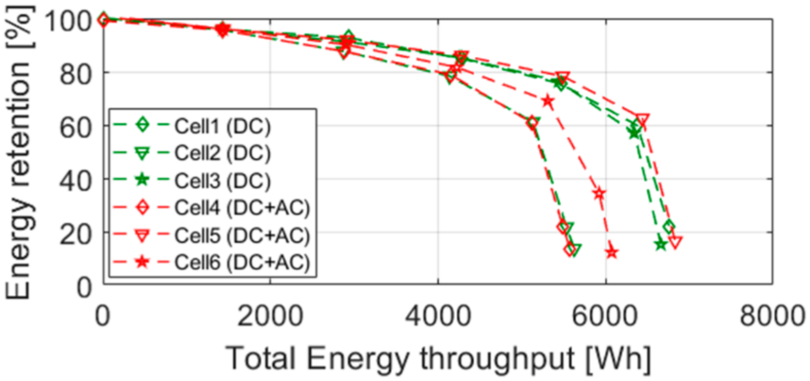
Distortions in harmony can cause an increase in temperature, which can hasten the deterioration of lithium-ion battery cells, hence shortening their lifespan and decreasing their capacity. In addition, thermal stress can make problems worse, such as lithium plating, which is the process by which lithium deposits on the surface of the anode. This can potentially result in short circuits and a decrease in the performance of the battery. Furthermore, the existence of harmonics might cause interference with the exact control algorithms that are utilized in battery management systems (BMS).

These algorithms are dependent on steady and predictable power inputs in order to optimize charging rates, monitor battery health, and guarantee safety.

Electromagnetic interference (EMI) is another issue that harmonics can cause; it can disrupt the functioning of delicate electronic parts in the car. Critical systems may become inefficient or break down as a result, endangering the vehicle's performance and safety. There are inefficiencies and increased operational expenses for charging infrastructure as a result of the lower power factor caused by the greater total harmonic distortion (THD), which means that more apparent power is needed to deliver the same amount of real power.



(**a**) Normalized capacity fade as function of number of cycles



(**b**) Energy versus total energy throughput

Fig 1.7 Normalized capacity fade as a function of number of cycles for normal condition group (i.e., cells 1–3) versus AC ripple condition group (i.e., cells 3–5) and retained energy versus total energy throughput.

Over time, the cumulative effects of harmonic distortion can lead to a significant decrease in the overall reliability and efficiency of the electric vehicle's charging system. This not only impacts the vehicle's operational readiness but also increases the total cost of ownership due to more frequent maintenance and battery replacements. In conclusion, harmonics during the charging process of lithium-ion batteries in electric vehicles present a range of adverse effects, from reduced efficiency and increased thermal stress to accelerated battery degradation and potential interference with vehicle electronics, all contributing to diminished performance and reliability.

1.6 HARMONIC FILTERING TECHNIQUES

It is crucial to account for reactive and harmonic current due to the extensive use of power electronic devices. One common approach to reducing harmonics in control systems is to use appropriate power conditioning techniques, like active and passive power filtering. Standard practice for lowering harmonics in power systems calls for the use of appropriate power conditioning techniques, like active and passive power filtering. The power factor and line current harmonics were improved using passive LC filters. Harmonic issues remain due to the system's tuning issues, parallel resonance, and incapacity to compensate for random frequency fluctuations in currents.

1.6.1 PASSIVE FILTERS

An inductance, capacitance, and resistance element comprise a passive filter. When compared to other methods of removing harmonic distortion, they are comparatively affordable; yet, they may have unintended consequences when used to remove harmonics. Passive filters have been widely utilized to accomplish multiple goals at once and to conform to the total demand distortion (TDD) requirements of IEEE Standard 519.

1.6.1.1 LC FILTERS

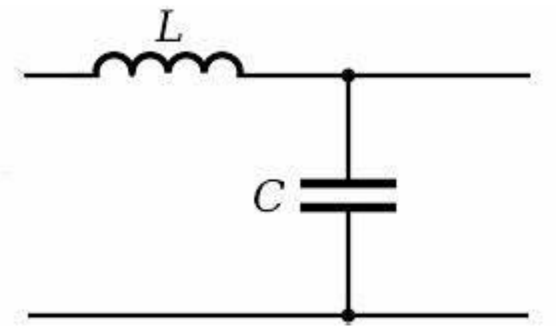


Fig 1.7 Passive LC Filter

1.6.1.2 SINGLE TUNED FILTERS

It's a single RLC circuit tuned to the frequency of one particular harmonic. An LC circuit resonates at particular frequency.

ω=2nf …………………………(3.1)

f=12(N)Lc ………………………(3.2)

At the frequency the filter circuit offer low impedance to harmonic f and high impedance to other harmonic. The capacitor value, which will be *used* in the single tuned filter previously calculated as:

$$Qc=P(Tan\theta 2-Tan\theta 1) \quad (3.3)$$

$$\omega=2nf \quad (3.4)$$

$$f=12nLC \quad (3.5)$$

Here,

$$P = (V)(I)\ Cos\theta_2$$

1.6.2 ACTIVE HARMONIC FILTERS

Contemporary active harmonic filters are multi-functional, unlike their passive predecessors, and can filter harmonics, dampen them, isolate and terminate them, control reactive power for power factor correction and voltage regulation, balance loads, reduce voltage flicker, and do all of the above, or any combination thereof. Manufacturers have introduced active filters to the market due to the substantial decrease in the cost of power semiconductor devices and signal processing devices.

Specifically, this work addresses hybrid active filters used to filter harmonics in three-phase diode rectifiers, as well as more general pure active filters used for power conditioning. In comparison to older passive harmonic filters that relied on capacitors, inductors, and resistors, modern active harmonic filters offer better filtering performance,

are physically smaller and have more versatile applications.

But even now, active filters aren't quite as bad as passive ones when it comes to operational expense.

It is possible to categorize pure active filters according on their circuit configuration, which can be either shunt (parallel) or series. Since series active filters are only good for harmonic filtering, shunt active filters are now the way to go due to their superior shape and function.

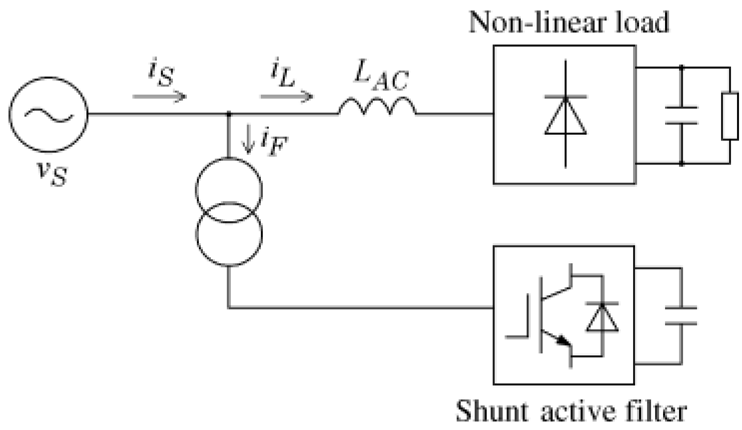


Fig 1.8 Single-phase or three-phase sunt active filter.

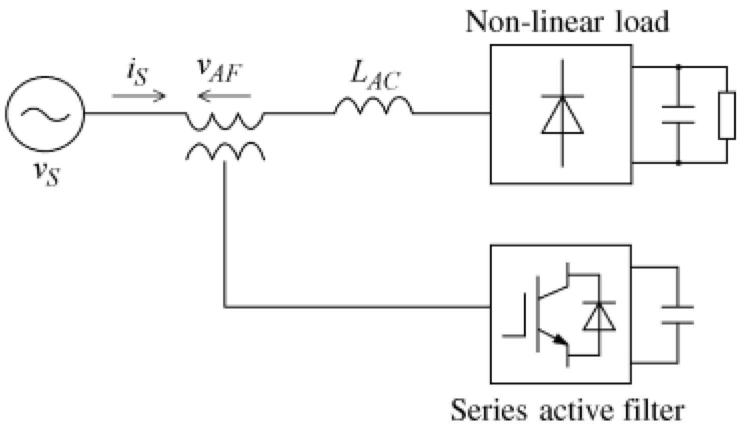


Fig 1.9 Single-phase or three-phase series active filter.

One major drawback of APFs is that their efficacy is highly dependent on the control approach used. Advanced control methods, including those based on synchronous reference frame theory or predictive control, are necessary for the accurate detection and real-time adjustment of second harmonic components. It can be difficult to develop and maintain these algorithms because of how finely tuned they need to be.

To reduce harmonics, people use shunt active power filters (SAPF). In order to eliminate harmonics, the SAPF injects an eliminating current that is equivalent to the harmonic current that the nonlinear loads inject. The current is injected, but its phase is opposite to the harmonic current introduced by the loads, even if their amplitudes are equal. Consequently, injecting this eliminating current into the system aids in power quality maintenance by reducing the impact of harmonic currents generated by nonlinear loads. In order for a SAPF to be effective, a firm method of control is required. There are normally three parts to the SAPF control plan. Following the first section's discussion on isolating harmonic currents is the DC-Link voltage regulation. Lastly, the control strategy incorporates the reference current version.

1.7 IMPACT OF LOW pf

The power factor of an electrical load can be calculated by dividing its active power consumption (in kilowatts) by its reactive power consumption (in kilovolt-amperes). We can categorize AC power into three distinct forms. The first is active power, which is also known as real power (P). A load's net energy transfer is represented by this. Voltage and current will oscillate in phase if the load is completely resistive, and the whole power flowing through the line will be active power. Furthermore, the power, denoted as Q, will be entirely reactive in the presence of a completely reactive load, such as an inductor or battery. The electric and magnetic fields of reactive components are created and maintained by this power. These fields cause the current to deviate from the voltage in a specific direction—90 degrees in the direction of capacitive loads and 90 degrees in the direction of inductive ones—as shown in Figure 6. Since the negative reactive power cancels out the positive reactive power, the total power produced by these reactive loads is zero.

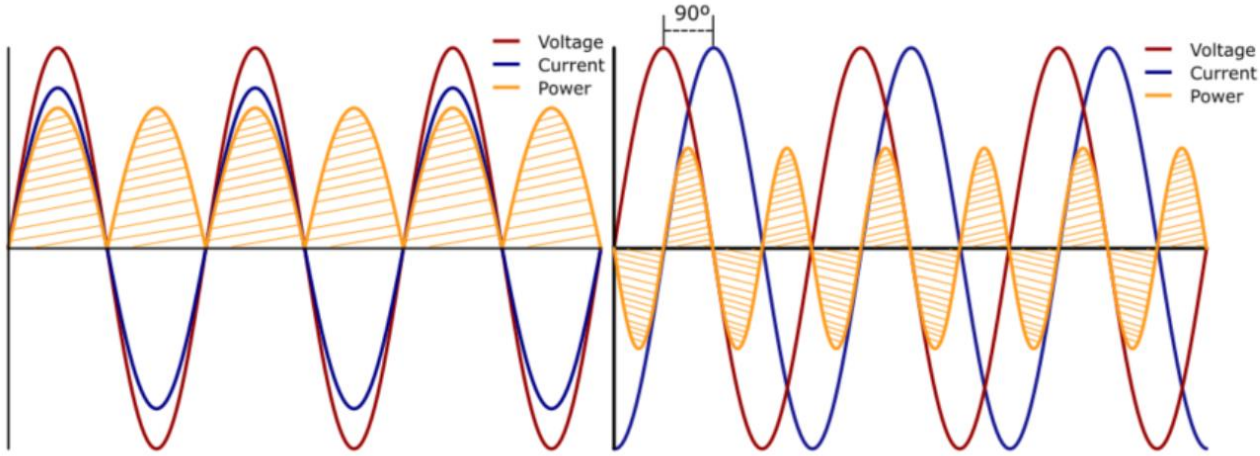


Fig 1.10 In-Phase V-I Waves and Associated Power (Left). V-I Waveforms and Associated Power for a 90° Phase Difference (Right)

As a function of voltage and current phasor angles, it is calculated as the cos of that angle. It should be mentioned that this definition does not apply in all cases, especially when nonlinear loads are present. All loads must adhere to the definition for it to be valid. With an ideal voltage supply, we consider a nonlinear load. A voltage signal is denoted as v(t) and a current signal as i(t) in this context.

It reveals the impact of load current on the supply system's efficiency and serves as a gauge for the current's efficacy in generating usable work output. This is the formulation of the system's true power factor (PF):

PF=cosϕ×Distortion power factor (dpf)

where cosϕ is the displacement power factor.

$I(t) = Io + \sum_{k=0}^{n} In(\sin n\omega t + \theta n)$ ……………………………………………………. (2.1)

$V(t) = Vp\ sin\omega t$ ……………………………………………….......................... (2.2)

Vpeak specifies the voltage's maximum value. Hn is the maximum value of the harmonic's component of the current, and $\emptyset n$ is the phase displacement of the harmonic components. The standard deviation of the current is expressed as an expression in mathematics:

$$\mathbf{I_{rms}} = \sqrt{I_O^{\ 2} + \Sigma_{n=1}^{\infty} I_n^{\ 2}} \qquad \text{……………………..……………………………………...(2.3)}$$

Solving for the electrical power factor is as simple as multiplying the displacement by the distortion's factor. The prior, shown as $k\emptyset$, is the trigonometric of the angle that separates both the voltage and current component.

…

$$K\Phi = \cos\Phi$$

In an ideal system, the current and voltage waveforms would be pure sinusoids. Electric motors, power electronics, and certain types of lighting are examples of non-linear loads that could introduce harmonics throughout real-world systems.

THD is typically expressed as:

$$THD\,(\%) = \frac{1}{\sqrt{g^2 - 1}} \qquad (2.5)$$

Where d is the distortion factor and can be defined as:

$$d = \frac{I1(RMS)}{\sqrt{I_O^{\ 2} + \sum_{n=1}^{\infty} I_n^{\ 2}}}$$

We can calculate the and define a equation as :

$pf = d \times k\Phi$

Power consumption in an alternating current (AC) circuit is minimized at its most efficient when the voltage and current are in phase. What we call the "distortion power factor" is actually the amount of power that gets reduced from a load current due to harmonic distortion.

Diode rectifiers with filter capacitors at their outputs draw current that isn't sinusoidal, distorting the power factor such that it's less than one and resulting in a low power factor. Traditional converters' poor input power factor and excessive overall harmonic distortion make basic diode rectifiers an inappropriate choice. Accomplishing rectification at approximately unity is essential for pulse width modulated rectifiers (PWM), which are an improved version of the conventional AC to DC diode rectifier.

1.8 BOOST POWER FACTOR CONVERTER

Electronic device makers employ a set of procedures known as power factor correction (PFC) to enhance the power factor of their products.

It has already been stated that when there is distortion or displacement in the signal, the power factor drops. Because capacitors pull the phase forward and inductors pull it back, the negative impact of displacement on the power factor may be easily remedied. To bring the current wave into phase with the voltage if it is trailing behind, all you have to do is add a capacitor with the correct impedance to the circuit.

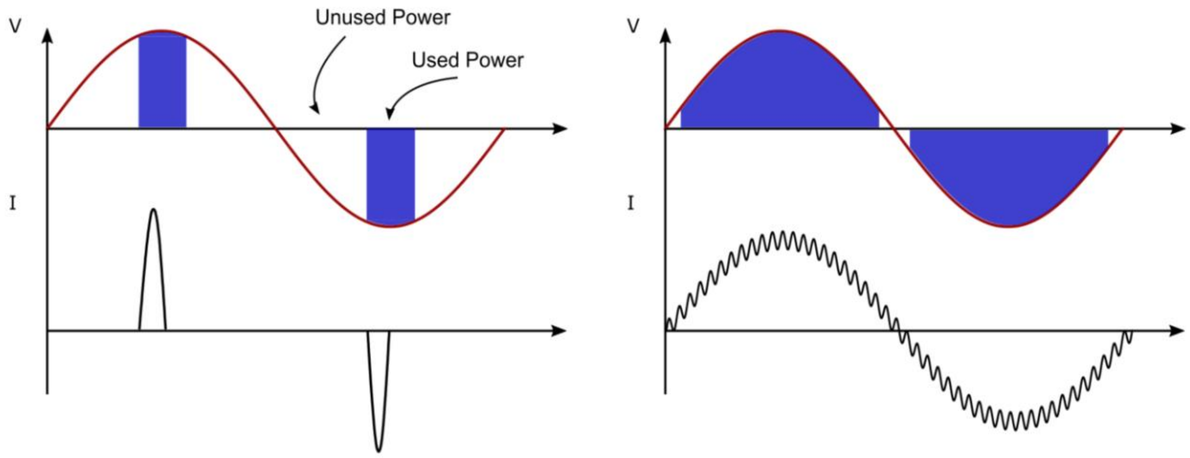


Fig 1.11 Low PF Power Transmission with No PFC (Left) and Power Transmission with Corrected Power Factor and PFC (Right)

In contrast, adjusting for the displacement factor in linear circuits is very simple compared to improving the system's distortion factor, which is typically present in nonlinear circuits. What we can do to achieve this is: Reduce harmonic content: Ignore the efficiency drop and focus on reducing harmonic injection into the grid through input filtering. Using a low-pass filter, passive PFC perfectly isolates the 50 Hz fundamental frequency while removing higher-order harmonics (see Figure 10). Since it requires large, heavy, and inefficient capacitors and inductors, it is not only impracticable for high-power systems but also ineffective at improving PF in real-world applications. Its usual usage is limited to uses involving powers below hundreds of watts.

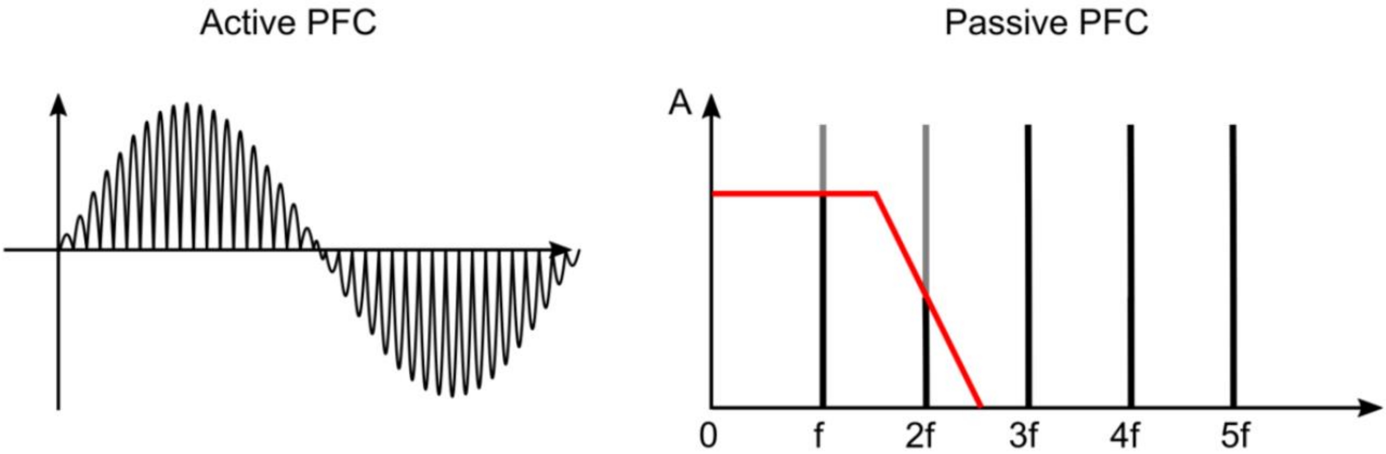


Fig 1.12 Active PFC in DCM Mode, Output Current Waveform (Left) and Passive PFC Filter Frequency Response (Right)

Power factor correction that is active? By modifying the shape of the current waveform, this approach makes it follow the voltage. By shifting the harmonics to higher frequencies, they become substantially easier to eliminate. A boost converter is the circuit that is most commonly employed in these situations. In a manner analogous to a transformer, this circuit increases the DC voltage while decreasing its current. A diode, an inductor, and a transistor make up the most basic boost converter.

The operation of the boost converter is divided into two stages. After the rectifier's output voltage has been applied, the inductor is charged in the first stage by closing the switch. A higher voltage is achieved at the output after the inductor releases the current it had stored in the prior stage and the switch is opened. While the inductor recharges, the voltage at the output is maintained by a capacitor that is charged by this current.

At sufficiently high switching frequencies, the inductor and capacitor are never completely discharged, and the output load voltage is always higher than the input voltage source. Constant conductivity describes this. The output voltage is directly proportional to the duration that the switch is closed, or the amount of time that the transistor is active. With the right controls, the input current wave can be sculpted into a sinusoid, which is the ratio of the time the shift is on to the complete switching cycle.

Still, CCM isn't used by every PFC converter. Another approach is available, which, at the expense of final PF quality, provides cheaper circuits and lower switching losses. Critical conduction mode (CCM) or boundary conduction mode (BCM) is a technique that switches the transistor at the exact moment the inductor is fully exhausted.
With zero-current switching (ZCS), the boost converter's diode can change polarity more quickly and readily, cutting down on the requirement for costly, high-quality components.

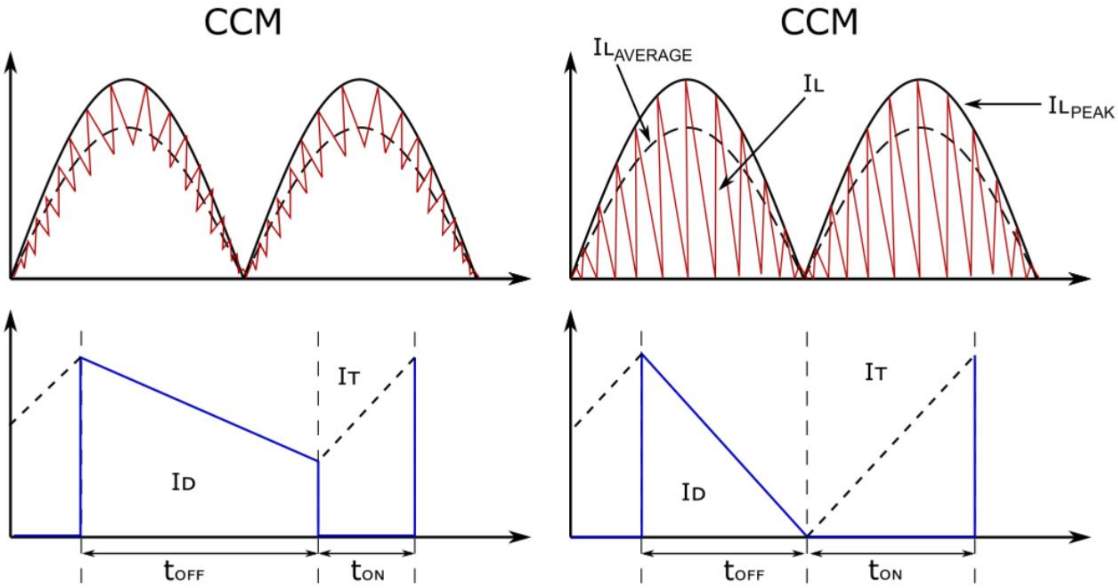


Fig 1.13 PFC Inductor, Transistor, and Diode Current for Continuous Conduction Mode (Left) and Boundary Conduction Mode (Right)

1.8.1 DESIGN OF BOOST PFC

As the switching device is turned off before the inductor current drops to zero, keeping the inductor current continuous, the energy in the inductor flows continuously during the operation of the boost converter in CCM (Continuous conduction mode) [11]. A rectifier circuit is used to transform alternating current (AC) from 230V to direct current (DC). A bridge rectifier is a circuit that uses four diodes in a closed-loop bridge design to produce an output voltage that is invertible regardless of the input polarity.

$$V_{DC} = \frac{2V_{\mathrm{m}}}{\pi} \tag{2.1}$$

By connecting a DC-DC Boost Converter to the rectifier's output, we may increase the voltage output above what the source voltage can provide. Given is the relationship between the source voltage and the voltage at the output:

$$V_{in} = \frac{1}{1-d} V_C \tag{2.2}$$

With Vin being the rectifier's input voltage to the converter and VC being the PFC Converter's output voltage, "d" represents the duty cycle. Obtaining the load value, which is assumed to be resistive, is the first step in designing and computing the filter circuit for a boost converter.

For the calculated R_L load the value of output filter circuit are,

$$L_1 = \frac{R_{L\max} D_{\min} (1-D_{\min})^2}{2 f_{sw}}$$

For the switching frequency of 100 KHz the value of L_1 600H

And capacitance C_{Link},

$$C_{Link} = \frac{D_{\max} V_C}{f_{sw} R_{L\min} V_{ripple}}$$

$$r_{L(\max,\min)} = \frac{V_O}{I_{O(\min,\max)}} \tag{2.3}$$

$$= \frac{400}{16.17}$$

r_L is calculated to be 24.737Ω.

1.8.2 Graphical Plots: Boost PFC Converter

Fig 1.14 and 1.15 demonstrate that the op voltage is constant at 400V with a fluctuation of 6Vpeak-peak. Additionally, the supply current is in phase with the voltage waveform and follows it synchronously. To provide clarity, the input current has been amplified by a factor of four from its original value.

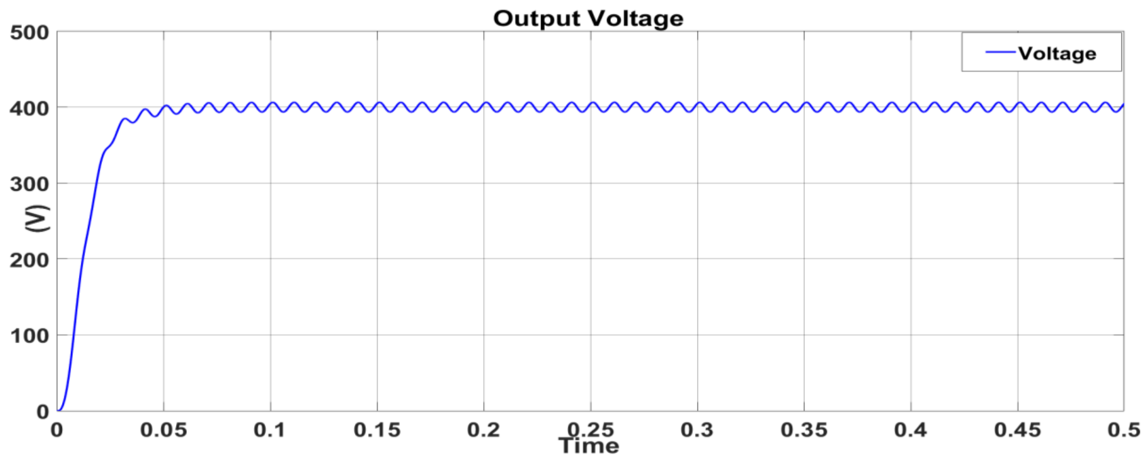


Figure 1.14: Waveform of output voltage

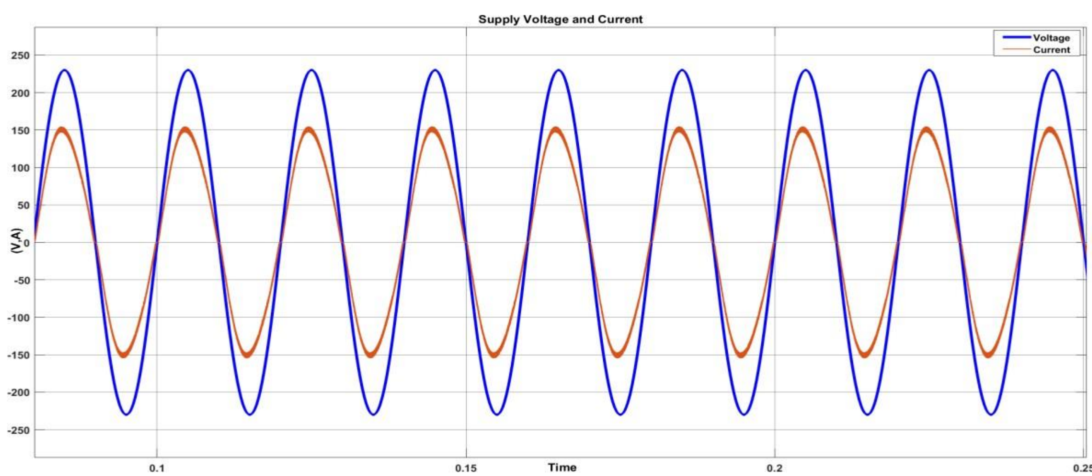


Figure 1.15 Waveform of op current and op voltage

fig 1.15 shows the results of the fast Fourier transform (FFT) analysis of the input current, which revealed a total harmonic distortion (THD) percentage of 5.67%. Equation 1.7 yields the pf value of 0.9979.

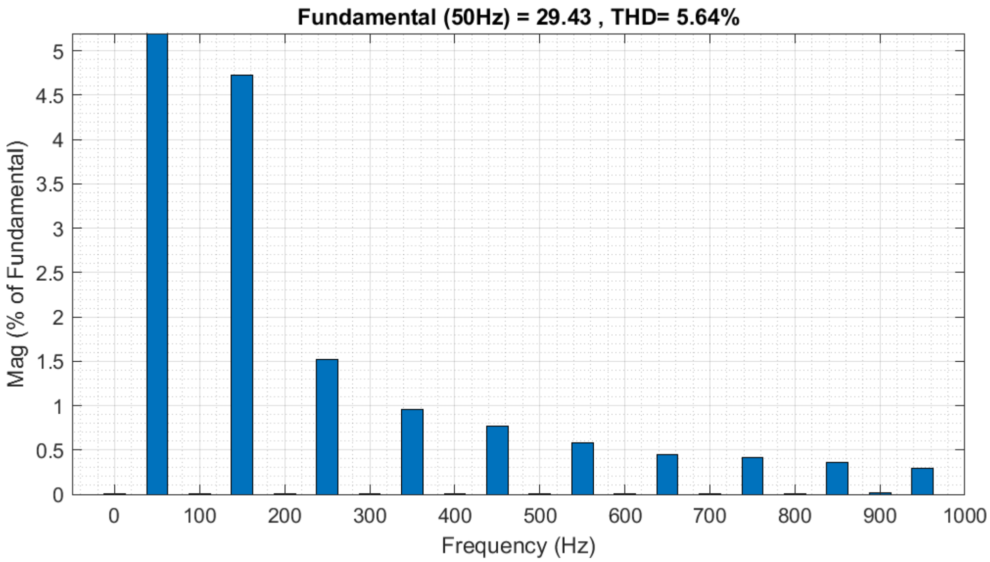


Figure 1.16 : FFT analysis of input current

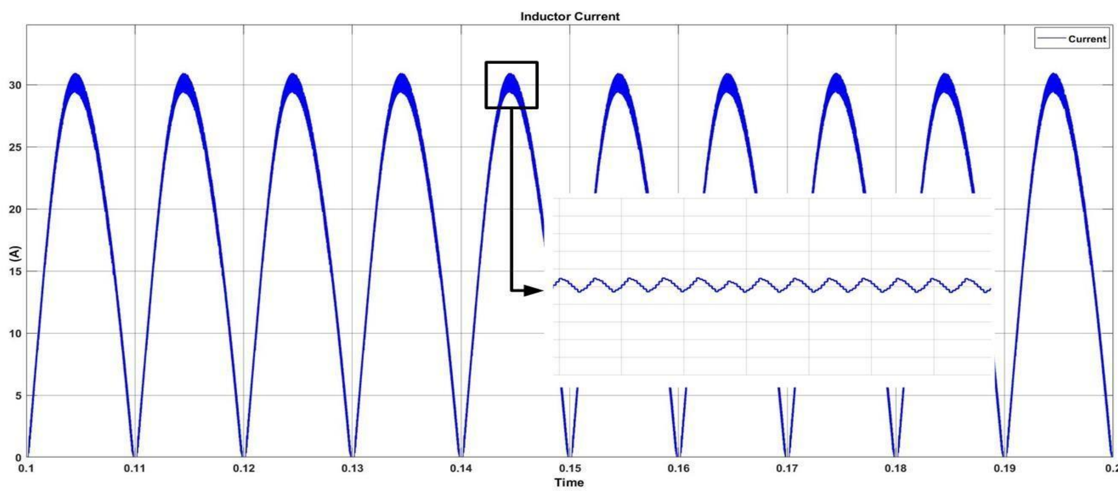


Figure 1.17 : Waveform of inductor current

Fig 1.17 depicts the waveforms of the input /output currents with different loads, ranging from 3400W to 1500W. Reducing the load from full to half likewise causes the output current to drop proportionally to half. The output voltage returns to the desired 400.5 V after a few cycles in 152 ms.

1.9 TWO STAGE EV BATTERY CHARGER

A typical two-stage EV charger is seen in Figure 1, which is a simplified block schematic. The first part of the process is a DC-DC boost converter that uses power factor correction (PFC) and an AC-DC rectifier. A DC-DC converter with galvanic isolation is shown in the next stage. Here, DC is first converted to AC, or high-frequency alternating current, and then returned to DC again. By following these steps, a transformer can be easily integrated into the system to offer isolation from galvanic current. In order to provide galvanic isolation, the DC-DC stage uses a full-bridge LLC resonant conversion device, which has four switches, four diodes, and an isolation transformer. The two-stage EV charger, which consists of an AC-DC converter and a DC-DC converter, is widely used but has a few limitations. Considerations like as size, performance, price, complexity, and efficiency all come under these constraints. Due to the high conversion losses, two-stage chargers initially fail to meet expectations. In this configuration, converting the alternating current (AC) to direct current (DC) and then tailoring the DC current to the battery's requirements are the two stages of power conversion.

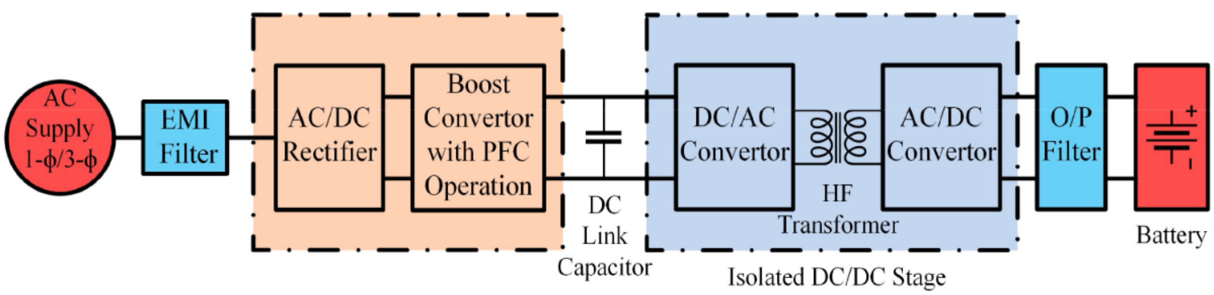


Fig 1.3 Generalized block diagram of a two-stage standard EV charger.

The charging system's overall efficiency is reduced because of the efficiency losses introduced by each conversion stage, which usually range from 2 to 5 percent each level. In conclusion, two-stage EV chargers are good at what they need to do—transform grid AC power into DC levels that EV batteries can use—but they aren't as great as more integrated options when it comes to efficiency, cost, complexity, size, and performance. To get around these limitations, power electronics have been developing more efficient, smaller, and lighter devices with better control systems; examples of this include integrated charger designs and single-stage converters.

1.10 SINGLE STAGE CONVERTER

The advancements that have been made in power electronics, like as single-stage converters or integrated charger builds, are aimed at overcoming these limitations by increasing efficiency, reducing size and weight, and simplifying control systems. Two-stage electric vehicle chargers are capable of performing the critical task of converting alternating current (AC) power from the grid into direct current (DC) levels that are adequate for electric vehicle batteries. However, when compared to more integrated options, these chargers have a number of shortcomings that make them less desirable. These drawbacks include efficiency, cost, complexity, size, and performance. Improvements in power electronics, such as single-stage converters and integrated recharge designs, are being made with the intention of overcoming these limitations by increasing efficiency, reducing size, and simultaneously reducing power consumption weight reduction, simplification of control systems, and reduction of low-frequency ripple at the source are all included. Nevertheless, studies have shown that the fluctuating current produced by the on-board charger at double the frequency of the power supply does not seem to have any noticeable detrimental effect on the performance and lifespan of lithium-ion batteries. This was recorded.

For lithium-ion battery chargers, when ripple at low frequencies is acceptable, several single-stage designs without electrolytic capacitors have been proposed. Rectification of the line voltage produces a low-frequency component, which the high-frequency transformer must carry. This leads to a significant increase in core volume and losses. Since the main winding voltage is twice the line frequency component, it generates a substantial quantity of magnetizing current in the transformer. Among the numerous suggested designs for one-stage EV chargers is an electrolytic capacitor-less AC-DC converter with high-frequency isolation that is compatible with electric vehicles and plug-in hybrids. A single-stage alternating current to direct current converter with high-frequency isolation and no electrolytic capacitors is one of several designs that have been considered for use in on-board PHEV and EV chargers.

Also available is the Single Stage AC-DC High Step-Down Bi-folding Converter for Onboard EV Chargers, which has Second Harmonic Reduction and Synchronous Rectification. With just one power electronics stage, a single-stage EV charger streamlines the AC-DC and DC-DC conversion processes, which has many benefits. This combination reduces the number of components and conversion steps, which improves overall efficiency by cutting down on the number of places energy can be lost.

In addition to making the system smaller and lighter, the simplified design cuts costs by reducing the number of components and complexity. This is especially helpful for car chargers that are installed on the vehicle. In addition, single-stage chargers are known to have better power density and dynamic response, which boosts performance and reliability while reducing challenges in thermal management. All things considered, single-stage chargers are the most practical and economical option for charging electric vehicles.

1.11 OBJECTIVE

The primary objective of this thesis is to create a charging system for electric vehicles using AC-DC converters that have great efficiency. The system will employ a moving average filter to control the current and aim to minimize second-order harmonics to ensure dependable functioning and improved power integrity. This thesis focuses on a novel approach that utilizes a moving average filter to reduce second-order harmonics in an electric car charger that uses an AC-DC converter. The objectives of this study are to demonstrate the expected improvements in power quality, efficiency, and overall performance.

1.12 OUTLINE OF THESIS

Here is the structure of the thesis:

CHAPTER 1: The first section introduces the reader to Electric Vehicle (EV) technology and offers a background on the significance of control structure and Battery Charging. Furthermore, the chapter explores the harmonic issues related to the charging of electric vehicle (EV) batteries.

CHAPTER 2: In this chapter, we will examine the literature review.

CHAPTER 3: This chapter focuses on the modeling and system configuration of the proposed single-stage AC-DC converter for electric vehicle charging applications.

CHAPTER 4: This chapter focuses on validating the results obtained from the simulation of a 6.1 kW electric vehicle charger.

CHAPTER 5: This chapter provides a summary of the contributions made by this thesis and emphasizes the possibilities for future research opportunities.

1.13 CONCLUSION

With an emphasis on reducing second-order harmonics using a moving average filter technique, this thesis offers a thorough investigation and design of an electric car charger based on an AC-DC converter. The thesis is structured in a way that makes the journey from basic ideas to specific implementation and validation easy to follow and understand.

Electric vehicles (EVs) and their underlying technologies are introduced in Chapter 1, which also emphasizes the significance of a solid control system. The article lays the groundwork by outlining the harmonic problems with charging EV batteries and stresses the need for efficient harmonic reduction to guarantee dependable charging procedures. In a later chapter, we will examine the AC-DC converter that uses Power Factor Correction (PFC) to transform the grid voltage into a usable DC voltage with lower order of current harmonics and high-power factor. The creation of the proposed charger is based on the exploration and simulation of various PFC setups. Methods for designing the AC-DC converter, such as SOGI-PLL, LC filters, and the moving average filter, are covered in a later chapter. If you want your charging system to work as intended and reduce harmonic interference, these parts are essential. A thorough comprehension of the design and operation of the complete charging mechanism is in this chapter. In conclusion, this thesis presents a new AC-DC converter design that incorporates a moving average filter, effectively mitigating harmonics in electric vehicle chargers. This work makes a substantial contribution to electric vehicle charging technology with its comprehensive investigation, design, and validation procedures, which will lead to EV chargers that are more efficient and dependable. Using this as a springboard, researchers might investigate the suggested approaches' potential for further improvement and expansion in future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 SURVEY OF LITERATURE

In Paper [1], this study examines the current state and execution of battery chargers, charging power levels, and infrastructure for plug-in electric vehicles and hybrids. Charger systems can be classified into two types: off-board and on-board. These types can further be distinguished by the direction of power flow, which can be either unidirectional or bidirectional. Unidirectional charging reduces the need for complex circuitry and simplifies the problems related to connections. Bidirectional charging enables the battery to feed energy back into the grid. Conventional on-board chargers limit power output due to limitations in weight, space, and cost. They can be incorporated into the electric propulsion system to mitigate these issues. The presence of charging infrastructure decreases the need for energy storage on the vehicle and lowers associated expenses. On-board charger systems can be either conductive or inductive. A high-capacity charger can be engineered to accommodate rapid charging rates and is not as limited by size and weight restrictions. The text discusses three power levels: Level 1 (convenient), Level 2 (main), and Level 3 (rapid). Future developments, such as the implementation of roadbed pricing, are discussed. The study examines different power level chargers and infrastructure configurations, comparing and evaluating them based on characteristics such as power capacity, charging duration, location, cost, equipment, and other relevant considerations.

The paper presents the following practical implications:

The performance of the battery is influenced by the characteristics of the charger and the infrastructure it is connected to. The integrated chargers provide affordable and efficient bidirectional fast charging with high power. Charging infrastructure decreases the need for energy storage on board and lowers associated costs. Standardizing regulations, implementing smart chargers, and advancing battery technology contribute to the improvement of electric vehicles (EVs).

The limitations are as follows:

1. Fast-charging stations cause an excessive burden on distribution equipment, leading to increased losses and voltage variations.
2. The widespread adoption of electric vehicles has a significant impact on the lifespan of transformers, distribution equipment, and conductors' capacity.

In paper, [2], This study demonstrates the efficacy of employing redundant states to equalize the voltages across the six capacitors of a seven-level inverter. In general, the presence of duplicate states is commonly linked to the space vector pulse width modulation (PWM) technique. The validation of the balancing method in our work is performed using the selective harmonics elimination PWM, which is particularly suitable for high voltage applications. Initially, switching angles are calculated for various modulation index values in order to eliminate harmonics in rows 5, 7, and 11. The proposed balancing algorithm is rather complex. It utilizes 300 switching states and 720 imbalance cases of the DC-link. To streamline the analysis of switching states, the inverter is represented using an analogous matrix model. The results indicate that DC-link balancing can be achieved without the need for any additional circuitry, while yet keeping the performance of SHE-PWM.

Practical Implications:

Validates DC-link balancing without additional circuits in seven-level inverter.

Achieves harmonic elimination and fundamental voltage control simultaneously.

Simplifies switching states analysis using an equivalent matrix model.

Limitations observed in this paper:

Complexity due to a large number of vectors in the study.

Resolution of four non-linear equations with four unknowns.

From Paper [3], This article provides an overview of the present state and application of battery chargers, charging power levels, and infrastructure for electric vehicles (EVs). The performance of a battery is influenced by both the kind and design of the battery, as well as the features of the charger and the charging infrastructure. The categorization of battery infrastructure and charging power levels consists of three types: Level 1, Level 2, and Level 3. Charger systems can be classified into two types: off-board and on-board. These systems allow electricity to flow in either one direction (unidirectional) or both directions (bidirectional). Unidirectional charging minimizes hardware needs, streamlines connector concerns, and generally decreases battery degradation. Bidirectional charging enables the battery to feed energy back into the grid. Conventional on-board chargers limit power output in order to comply with limitations on weight, space, and cost. One potential solution to these issues is to utilize the electric drive system as a built-in charger. Integrated chargers offer a significant benefit in that they support low-cost high-power bidirectional rapid charging (Levels 2 and 3) with unity power factor. The presence of a charging infrastructure decreases the need for energy storage on the vehicle and lowers associated expenses. On-board charger systems can be either conductive or inductive. Inductive charging holds the potential to sustain active roadbed systems in the long run. These are now being examined by multiple research teams. Different charger power levels and infrastructure configurations were presented and compared, taking into account parameters like as power capacity, charging duration, location, cost, compatibility, required equipment, and other relevant considerations. The success of electric vehicles (EVs) relies on the standardization of needs and infrastructure decisions, the implementation of efficient and intelligent chargers, and the advancement of battery technologies.

Paper [4], here the study can be categorized into two distinct classes based on their harmonic characteristics: current-source type loads and voltage-source type loads. The use of voltage source type nonlinear loads is becoming more prevalent, making the reduction of harmonics caused by these loads a significant concern. Practical evidence has demonstrated that hybrid active power filters are an effective option in this situation. The topology of these filters may effectively reduce both current-source and voltage-source harmonic currents without requiring any modifications to the hardware or software structure. The control technique, in conjunction with the active impedance concept, can effectively correct many harmonic frequencies using a single capacitor bank as a passive structure, eliminating the requirement for a tuned structure for each frequency.

Practical Implications of this paper :

1. Hybrid active filters effectively mitigate harmonic currents from various nonlinear loads.
2. Control strategy compensates multiple harmonic frequencies with one capacitor bank.

Limitations:

1. Shunt active filters are ineffective for voltage-source type nonlinear loads.
2. Passive filters have drawbacks like component limitations and system resonance risks.

In Paper [7], The purpose of this study is to create the output impedance model of the SCC (Single-Stage AC-DC Converter) in order to assess the low-frequency output voltage ripple. Analyzed was the closed-loop output impedance of the converter using VMC, from which the relationship between the magnitude of output impedance and output voltage ripple was produced. The low-frequency ripple voltage can be accurately assessed using the output impedance model. Another benefit is that the technique of tailoring the output impedance using virtual impedance may be obtained by utilizing the output impedance model. The virtual impedance was implemented in this paper using an inner current feedback loop, also known as ACMC. In addition to peak current management, load current feedforward control, and nonlinear control may also be utilized as the virtual impedance. The analysis showed that the output impedance shaping method using Active Common Mode Control (ACMC) has superior suppression of low frequency ripple compared to Voltage Mode Control (VMC). The flyback PFC converter was tested with the buck SCC prototype to validate the accuracy of the theoretical analysis.

The Practical Implications found in the paper is as below:

1. Evaluates low-frequency output voltage ripple in single-stage ac-dc converter.
2. Confirms theoretical analysis through experiments with buck SCC prototype.

Limitations:

1. Single voltage feedback loop insufficiency due to Tv1(j2pf2nd) gain.
2. Design trade-off between efficiency and capacitor size optimization.

The paper [8], the primary aim of this study was to provide control design principles for a standard MAF-based Phase-Locked Loop (PLL). The study commenced with a comprehensive overview of the MAFs, which was subsequently followed by their implementation in discrete time. The practical problem related to the MAFs, namely their frequency-dependent attenuation properties, was subsequently addressed in a concise manner. Possible strategies to address this difficulty include adjusting the sample frequency and the order of the MAF online, utilizing the mean value approach, the weighted mean value method, and interpolation techniques. In order to offer a clear framework for choosing the most suitable approach for a certain application, a thorough comparison of different methods was also conducted. The paper provided an overview of several MAF-based Phase-Locked Loops (PLLs). Subsequently, two systematic approaches were introduced for designing the control parameters of a standard MAF-based PLL. One technique is applicable when a PI-type LF is used in the PLL, while the other method is suitable when a PID-type LF is employed. Ultimately, the study examined the effectiveness of a finely adjusted MAF-based Phase-Locked Loop (PLL) when employing the Proportional-Integral (PI) type Loop Filter (LF) in comparison to the results obtained utilizing the Proportional-Integral-Derivative (PID) type LF. Experimental evidence has demonstrated that the PID-type low-pass filter (LF) is capable of achieving a greater bandwidth, resulting in a faster dynamic response, compared to the PI-type LF. However, this advantage comes at the expense of decreased noise immunity and disturbance-rejection capability.

Practical Implication:

1. Guidelines for MAF-based PLL design and control parameters selection.
2. Comparison of PI-type LF and PID-type LF performance in PLL.

Limitations:

1. Frequency-dependent attenuation is a limitation of MAFs.
2. Variable sampling rate PLLs have limitations in grid frequency.

This paper [10], Two innovative hybrid topologies, characterized by their uncomplicated construction and excellent performance, are introduced. Driving both switches in the converters is straightforward, and the power density and conversion efficiency can be enhanced by placing the EMI filters on the dc side. The enhanced peak current control system ensures that the power factor (PF) remains above 0.9 across the whole input voltage range. Additionally, the input current effortlessly complies with the IEC61000-3-2 Class C restrictions, making it highly appealing for industrial applications such as LED drivers.

The paper focused on:

Focus on hybrid PFC converters, addressing low PF and harmonic issues.

Proposes hybrid topologies with improved peak current control scheme.

Emphasizes high PF under universal input range and IEC61000-3-2 Class C limits.

The practical Implications are:

1. Improved converters with high PF suitable for LED drivers.
2. Experimental verification of theoretical analysis with 150-W prototypes.
3. Topology 11 recommended for non-floating output in industrial applications.

The limitations of this are:

1. Buck PFC has low PF and poor harmonic performance at low input.
2. Harmonic performance limitations addressed through hybrid PFC converter topologies.

In paper [11], here the study uses a fixed-step direct-control incremental conductance method, this research presents simple moving voltage average (SMVA) methodologies.

Practical Implications are,

1. Improved PV system performance with higher tracking accuracy and stability.
2. Enhanced efficiency under varying environmental conditions with faster response time.

Limitations are:

1. Oscillation and efficiency differences in fixed step control methods
2. Small marginal error adjustment in incremental conductance method

2.2 CONCLUSION

The literature study offers a thorough comprehension of the progress made in power electronics, with a particular focus on enhancing efficiency, reliability, and performance in electric vehicle (EV) charging systems and associated technologies. In their study, Yilmaz and Krein (2013) provide a comprehensive framework that outlines different levels of charging power and battery charger topologies necessary for a reliable electric vehicle (EV) infrastructure. They specifically emphasize the efficiency improvements in the AC-DC and DC-DC conversion processes. Imarazene et al. (2016) and Busquets Monge et al. (2007) investigate the issues of voltage stability and harmonic distortion in inverter systems. Imarazene proposes a technique called selective harmonics elimination PWM, while Monge suggests a method called virtual space vectors. Both techniques aim to address the challenges of maintaining voltage balance and optimizing spectral performance in high-power applications. Nguyen et al. (2022) propose a streamlined and effective inverter design that combines boosting and inverting functions into one stage, offering a realistic approach for achieving high power density and efficiency. Gonzatti et al. (2013) specifically examine the use of a hybrid active power filter to compensate for harmonics.

This technique successfully reduces harmonic distortion and improves power quality in different load situations. Xu et al. (2021) examine phase-locked loops based on SOGI (Second Order

Generalized Integrator) for the purpose of achieving dependable grid synchronization even in situations with varying conditions. Their analysis yields significant design suggestions for ensuring the stability of the grid. Cai et al. (2019) and Golestan et al. (2014) discuss different aspects of power management in PLLs. Cai et al. focus on decreasing low-frequency output voltage ripple, while Golestan et al. concentrate on managing harmonics.

Both studies provide valuable insights on how to minimize ripple and improve synchronization, which ultimately leads to increased efficiency and durability of converters. Zhao et al. (2014) investigate the performance of hybrid step-down PFC converters in single-phase applications. They focus on achieving a balance between power factor and efficiency by exploring several topologies and control approaches. In their recent study, Dang and Ruan (2020) propose a contemporary method for compensating harmonics in power systems. They provide evidence of its efficacy in strengthening the overall performance of the system and emphasize the significance of accurate harmonic current compensation in improving power quality.

These studies collectively showcase significant progress and creative solutions in power electronics, tackling essential obstacles and offering useful knowledge for the development of a sustainable and efficient electric vehicle infrastructure.

CHAPTER 3

MODELLING AND SYSTEM CONFIGURATION

3.1 INTRODUCTION

In this chapter we will look at the proposed Model for the single stage AC-DC Boost PFC with second harmonic mitigation with Active Filters. AC-DC conversion mandatorily leave the second-order harmonic footprints in the currents on the DC bus which has large amount of ripple voltages calling for implementation of large DC-capacitance, which not only results in poor device power density but also alter the characteristics of the converter to a voltage source not suitable for eV charging applications which demands for current converters.

The current harmonic pollution poses a huge threat while charging of batteries in terms of stability, safety, and efficient operation even executing as front-end stage for the cascaded buck type converter. This paper presents a new technique to extract the second order harmonics component from the current at the rectifier's output using low computation and easily implementable different bandwidth moving average low pass filters. The second harmonic current compensator (SHCC) using single phase self-supporting voltage source inverter eliminates the second harmonic currents (SHC) in the output side without influencing the PFC configuration on the AC side, thus drastically reducing the size of the capacitance of the filter.

The analysis of filtering technique and configuration of the compensator along with control of PFC is dealt in detail. The simulation results demonstrate the ability of the proposed compensator works well with PFC AC-DC converter to offer current based control suitable for battery charging without large 2^{nd} harmonic ripples. The simulation and analysis is performed by keeping the devices and parameters in their ideal nature.

3.2 SINGLE STAGE AC-DC CONVERTER WITH BOOST PFC

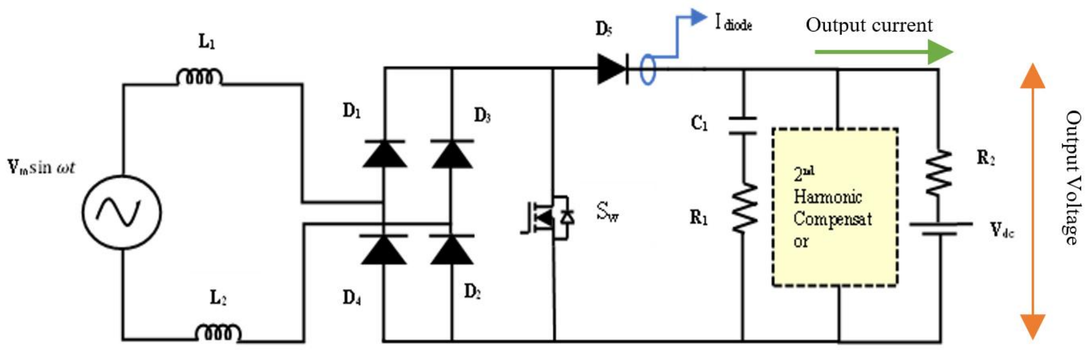


Fig 3.1 Circuit Diagram for AC-DC Boost PFC with second harmonic compensation

The setup of the AC Mains (230V rms, 50 Hz) feeding the AC-DC-Boost PFC and the harmonic compensator is shown in Fig. 3.1. This allows the lithium-ion battery to be charged under continuous current control mode. The moving average-based double cascaded LPF enables complete segregation of the second harmonic component at the DC side.

A harmonic compensator charges a 400V DC Li-ion battery in current control mode after the PFC Boost converter runs with a constant current flow, which facilitates a better reduction in filter size.

The active ripple compensator consists of self-balanced H-Bridge inverter which is used in order to mitigate the dominant second harmonics component at the DC side of rectifier.

The capacitor voltage is being maintained by PID controller.

Working of second harmonic segregation : The H-Bridge inverter based SHC which traces the second harmonic component which is being fed from the cascaded LPF. The current I_{inject} is tracked by the H-Bridge inverter and I_{cap} is maintained by PID tuned controller, which is shown in Fig 2(a). In this approach less complexity is involved in addition with fast and accurate output. In this section, first the control method has been explained followed by the filter's functioning.

3.3 HARMONIC SEGREGATION

The current I_{inject} is tracked by the H-Bridge inverter and I_{cap} is maintained by PID tuned controller. In this approach less complexity is involved in addition with fast and accurate output. The H-Bridge inverter is connected in parallel with the AC-DC Boost-pfc rectifier output and the output of the inverter injects the harmonic component which is of 100Hz frequency at the rectifier output to compensate the harmonics.

The capacitor C_H which is of 470μF is pre-charged to 410V. The V^*_c = 500 V and V_c = 410 V. I_{cap} is the output from the PID controller which is 180° out of phase with the second harmonic components, it charges and discharges the C_H capacitor. The output current, I_a of the rectifier is then fed back at the output side of rectifier.

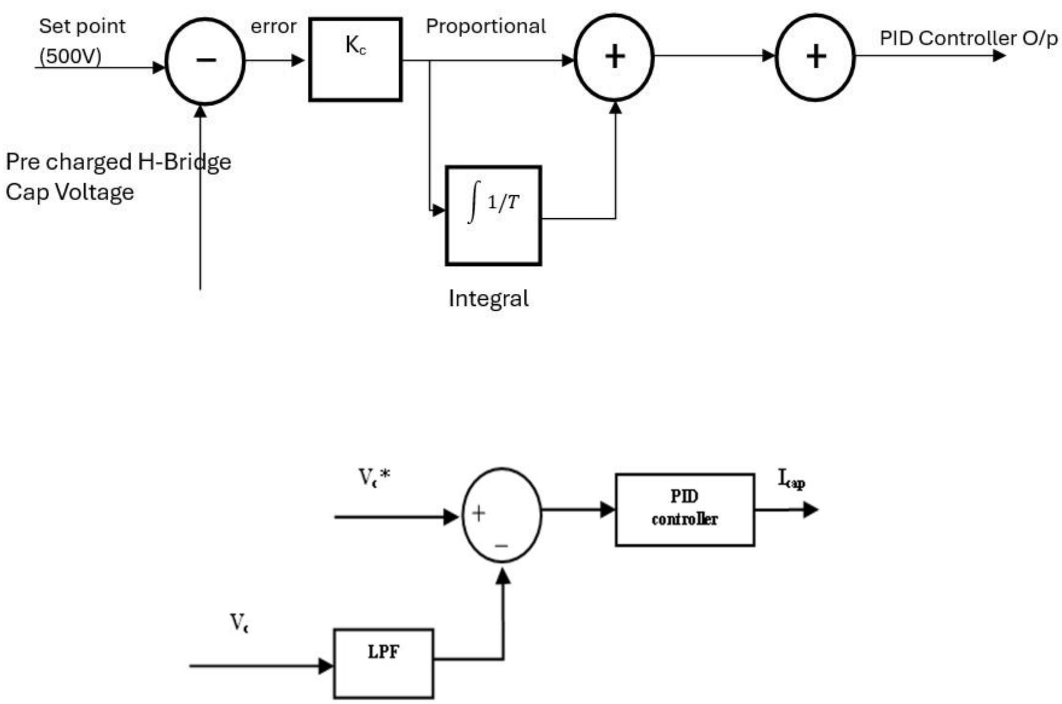


Fig 3.2 Block diagram of Control methodology

Fig 3.2 shows the H-Bridge inverter based SHC which traces the second harmonic component at the DC side of the rectifier, which is being fed from the cascaded LPF.

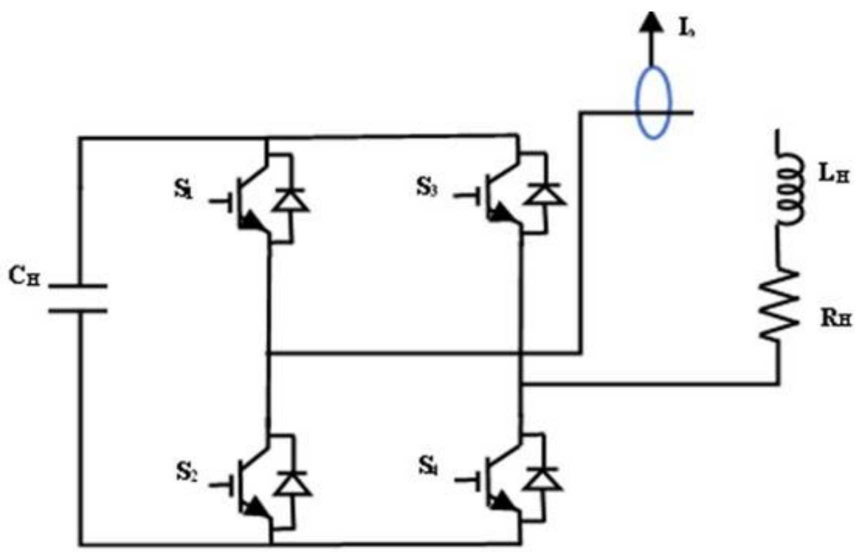


Fig 3.3 Circuit Diagram of H-Bridge Inverter

Fig 3.3 shows the diagram where current control mode is used. The expectation current waveform is as reference signal and the actual current is as feedback signal. Hysteresis current control tracks the reference waveform is decided by comparing the instantaneous current value and the reference one to control output states of power switches. When the current rises to the upper threshold value, the hysteresis comparator output is low level, and the switch should turn off then the actual current would decrease. Conversely, the current declines to a floor threshold value $I_{(mini)}$, the hysteresis comparator outputs are high level, the switch should turn on and the current would ascend to $I_{(max)}$.

3.3.1 ACTIVE POWER FILTER

Active power filters are considered superior to passive filters primarily due to their ability to address resonance problems and effectively mitigate harmonics present within electrical systems. Resonance, a phenomenon where certain frequencies amplify vibrations, can cause significant disruptions and inefficiencies in power systems. Active filters use electronic control mechanisms to dynamically counteract these harmonics, ensuring smoother operation and improved power quality.

Despite these advantages, the widespread adoption of active filters is hindered by their high cost. The sophisticated technology and components required for active filtering systems significantly drive up the expense, making it impractical for many applications, particularly those with budget constraints.

To bridge this gap, the concept of hybrid active filters has been introduced. Hybrid active filters integrate both passive and active filtering techniques, leveraging the strengths of each. Passive filters, which are less costly and simpler in design, handle the bulk of the harmonic filtering. Active filters then supplement this by targeting and mitigating the remaining harmonics and resonance issues that passive filters cannot fully address.

This combination creates a cost-effective solution that still provides a high level of performance in harmonic elimination. By using passive components to deal with most of the harmonics, the overall cost is kept lower, while the active components ensure that any residual issues are effectively managed. This hybrid approach strikes an optimal balance between cost and efficiency, making it an attractive choice for many power systems seeking to enhance their harmonic mitigation capabilities without incurring prohibitive costs.

Existing studies primarily focus on the harmonic current detection of Active Power Filters (APF). The real-time and accurate extraction of the compensating current is crucial for APF control. Currently, harmonic current detection methods are mainly categorized into two domains: frequency domain and time domain.

In the frequency domain, harmonic current detection typically employs fast Fourier analysis. This method involves sampling the voltage or current, performing A/D conversion, and then conducting Fourier analysis to determine the phase coefficients and amplitude of each harmonic order. However, this approach is slow and has a significant time delay, leading to poor real-time performance.

In the time domain, harmonic current detection methods are based on either p-q theory or ip-iq theory. The p-q theory is a fundamental method for harmonic current detection and extraction but is only applicable when the voltage in a three-phase three-wire system is symmetrical and undistorted. Consequently, the improved ip-iq algorithm is the most widely used method in APF for utility grids with voltage distortion and asymmetry. With appropriate modifications, it can be applied to three-phase four-wire systems.

In the ip-iq harmonic current detection circuit, the DC variables ip and iq are obtained through a low-pass filter (LPF). The fundamental active currents of the three phases are then extracted using inverse coordinate transformation. The harmonic and reactive currents are derived by subtracting the fundamental active currents from the grid currents. However, research indicates that the accuracy and response rate of this detection method are significantly influenced by the performance of the LPF. Therefore, an improved moving average filter (MAF) has been proposed. Selective harmonic identification algorithms are based on this MAF.

Paper [9] introduced the principle of harmonic current detection in the dq synchronous rotating frame and the LPF based on the moving average algorithm. This approach aims to enhance the accuracy and efficiency of harmonic current detection in APF systems.

3.3.2 TWO POINT MOVING AVERAGE FILTER

The LPF used here in the Model uses the concept of Moving average filter (MAF). The MAF-SHC operates based on the principle of a moving average filter. MAFs are linear-phase finite-impulse-response (FIR) filters that can act as ideal low-pass filters (LPFs) if certain conditions hold.

It extracts the second harmonic component by averaging the instantaneous power signal over a specified time window. This filtered signal is then used to generate compensating currents that are injected into the system. By generating opposing currents with identical frequency and amplitude as the second harmonic component, the MAF-SHC cancels out the distortion, resulting in a cleaner power waveform.

They are easy to realize in practice and are cost effective in terms of the computational burden. In this section, the continuous-time description, and the discrete-time realization of MAFs are presented.

Not difficult to understand, the average value of a periodic AC signal (high frequency signal) in a fundamental period is zero, while the average value of a DC signal (low frequency signal) in a fundamental period is DC signal itself. Thus, averaging operation is equivalent to a low-pass filter for a periodic input signal.

As its name suggests, a moving average filter (MAF) creates each point in the output signal by averaging a number of its input signal points. Refer to Fig. 5. MAF can be thought of as a window of a given size (N in this case) that moves one element at a time along the array formed by the input signal. The MAF's result is the average of every element in the current window.

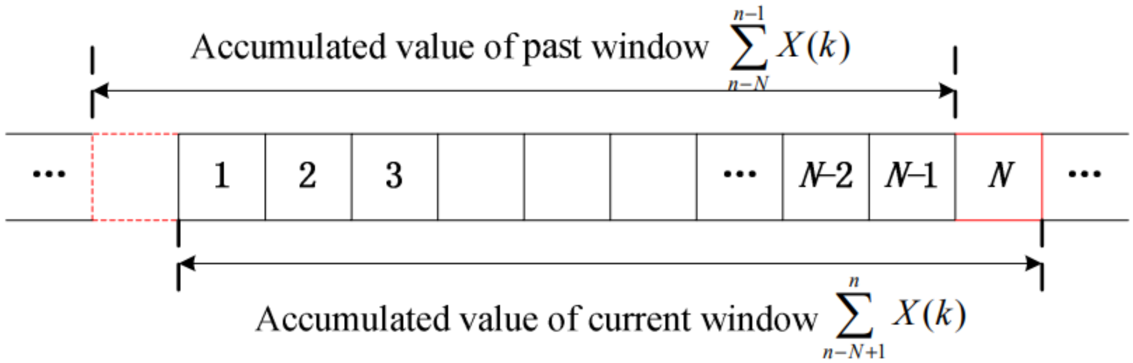


Fig 3.4 . Diagrammatic description of moving average filter (MAF)

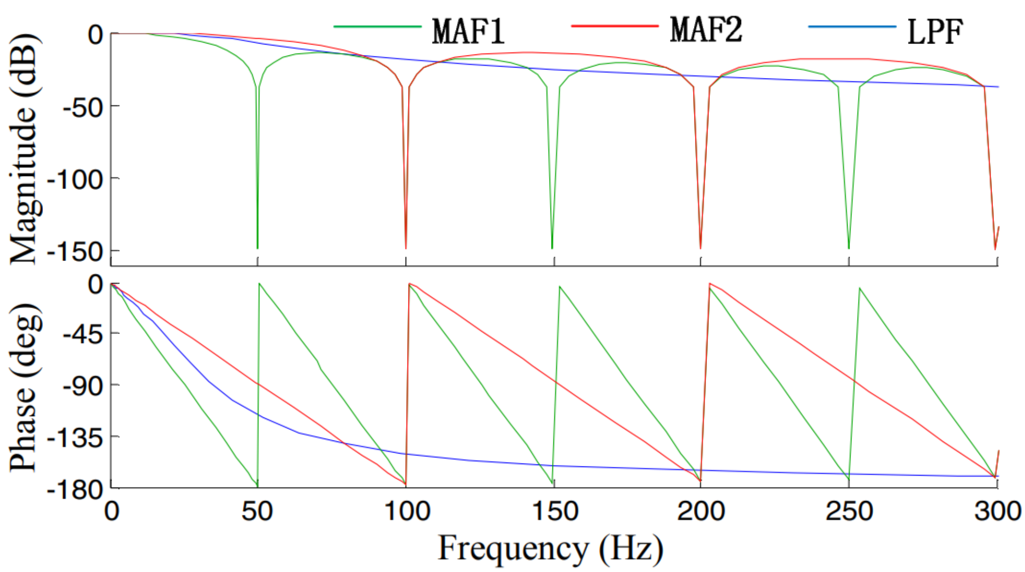


Fig 3.5 Bode Plot of Moving average filter and Low pass filter (LPF)

From Figure 3.5, it can be inferred that the Moving Average Filter (MAF) exhibits low-pass characteristics: it has zero attenuation and no phase delay at very low frequencies. At high frequencies, MAF1 rejects all multiples of the fundamental frequency, including both even and odd harmonics, while MAF2 specifically suppresses the even harmonics. Notably, MAF achieves a much higher attenuation ratio for undesired harmonics, both even and odd, compared to a second-order Low-Pass Filter (LPF). In other words, MAF demonstrates superior harmonic elimination performance compared to a second-order LPF.

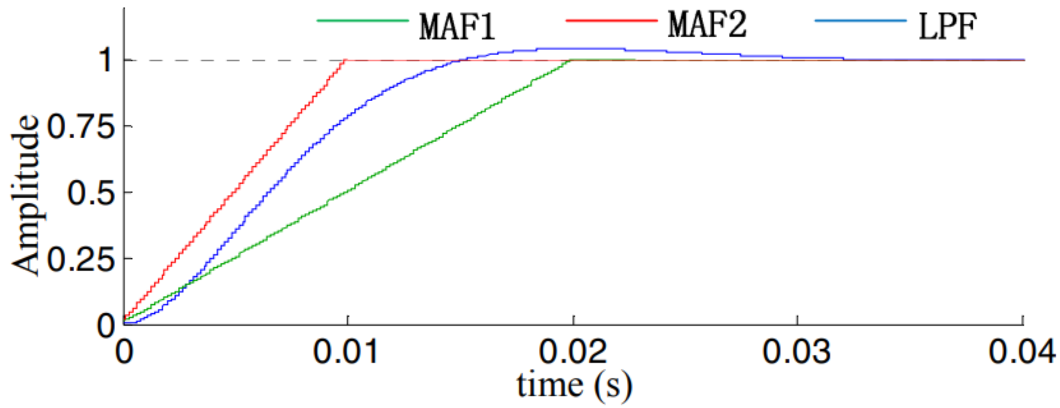


Fig 3.6 Step response of moving average filter

Continuous-Time Description of MAF with the input signal x(t) and the output signal $x_o(t)$ can be described in continuous-time domain by

$$x_o(t)= \frac{1}{Tw} \int_{t-Twin}^{t} x(\tau)\, d\tau \qquad (3.6)$$

where T_{win} is referred to as the length of window.

MAF transfer function is given by

$$G_{MAF}(s) = \frac{xo(s)}{x(s)} = \frac{1-e^{-Twin\, s}}{Twin\, s} \qquad (3.7)$$

The transfer function shows that the MAF requires a time equal to its window length to reach steady-state condition. Therefore, the wider the window length, the slower the MAF transient response.

Equation (3.6) defines the MAF in the continuous-time domain. However, to realize it in practice, a discrete-time definition is required. If the window length of the MAF contains N samples (N is an integer which, as we will see later, determines the MAF order) of its input signal, i.e., $T_{win} = NT_s$ where T_s is the sampling time, the discrete-time description of MAF can be obtained as follows:

$$x_o(k) = \frac{1}{N}\sum_{i=0}^{N-1} x(k-i) \tag{3.8}$$

where x(k) is the sample current.

The difference equation (3.9) can be expressed in Z-domain as

$$\begin{aligned} X_o(z) &= G_{MAF}(z)\, X(z) \\ &= \frac{1}{N}\left(X(z) + z^{-1} X(z) + \ldots + z^{-(N-1)} X(z)\right) \\ &= \left(\frac{1}{N}\sum_{i=0}^{N-1} z^{-i} \right) X(z) \\ &= \frac{1}{N}\, \frac{1-z^{-N}}{1-z^{-1}}\, X(z) \end{aligned} \tag{3.9}$$

In the simulation Moving average filter is used, and the results are verified with the simulation**.**

3.4 CONTROL METHODOLOGY

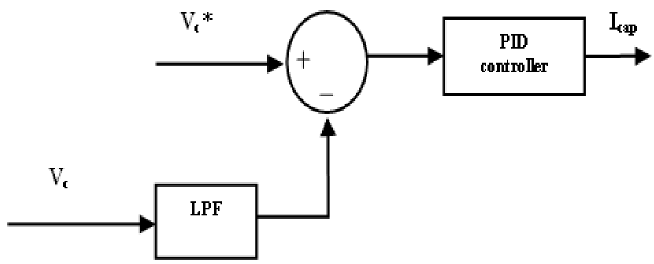


Fig 3.7 Block diagram of output and reference volatage fed to the LPF followed by PID

PID Controller : Sustainable power electronics are utilized to enhance power loss reduction and energy efficiency. Sustainable power electronics devices are utilized to enhance power quality in distributed generation, as per reports. Sustainable power electronics can effectively address problems related to sag, swell, and harmonics. Proportional-integral-derivative (PID) control is a highly successful solution to various control challenges in real-world applications. It does this through its three-term functionality, which effectively manages both transient and steady-state responses.
The aforementioned three studies provide unequivocal evidence that sustainable power electronics components are important for contemporary power systems.
DC electricity can be generated by employing a single-phase rectifier to convert AC electricity.
Diodes are essential components of rectifiers. The rectifier utilizes diodes for its switching mechanism. The rectifier will be regulated by diodes to deliver the intended output.
Rectifiers are also utilized in high voltage DC transmission lines.
The proportional-integral-derivative controller (PID controller) is a frequently used feedback mechanism in the control loop of industrial control systems. A PID controller calculates the error value by comparing the measured process variable with the desired set point. The controller adjusts the process by manipulating a controlled variable in order to minimize the error. The PID controller algorithm, sometimes referred to as third-term control, consists of three unique constant parameters: a proportional value (P), the integral value (I), and a derivative value (D)

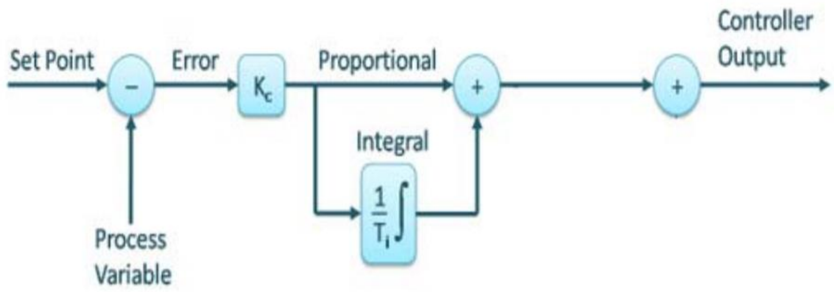


Fig 3.8 Control Strategy of PI Controller

P represents the current error, I is determined by the accumulation of past errors, and D is estimated based on the current rate of change, representing future errors. This rectifier commonly utilizes a Proportional-Integral-Derivative (PID) controller as its control mechanism. Nevertheless, the intricate and nonlinear nature of the existing power grid might exceed the capabilities of conventional PID controllers, particularly when additional advanced technologies are integrated into the grid.

As a consequence of this, it is unavoidable to structure the PID controller design around the intelligent technique. Because derivative action is susceptible to measurement noise, the absence of PI controllers leads to an integral term, which may result in a control action that prevents the system from reaching its goal value. This is because the integral term produces an integral term. Among the most important uses of output power augmentation in three-phase rectifiers are transmission grid and microwave communications, electric cars, and battery charging in commercial applications.

1.14 SECOND HARMONIC INJECTION

In this method, second harmonics are injected into the system to mitigate harmonic content. The injection occurs on the DC side, where the segregated second harmonic content is introduced out of phase. The advantages of the current injection technique include being a direct (non-iterative) and computationally efficient solution, capable of managing various harmonic sources simultaneously.

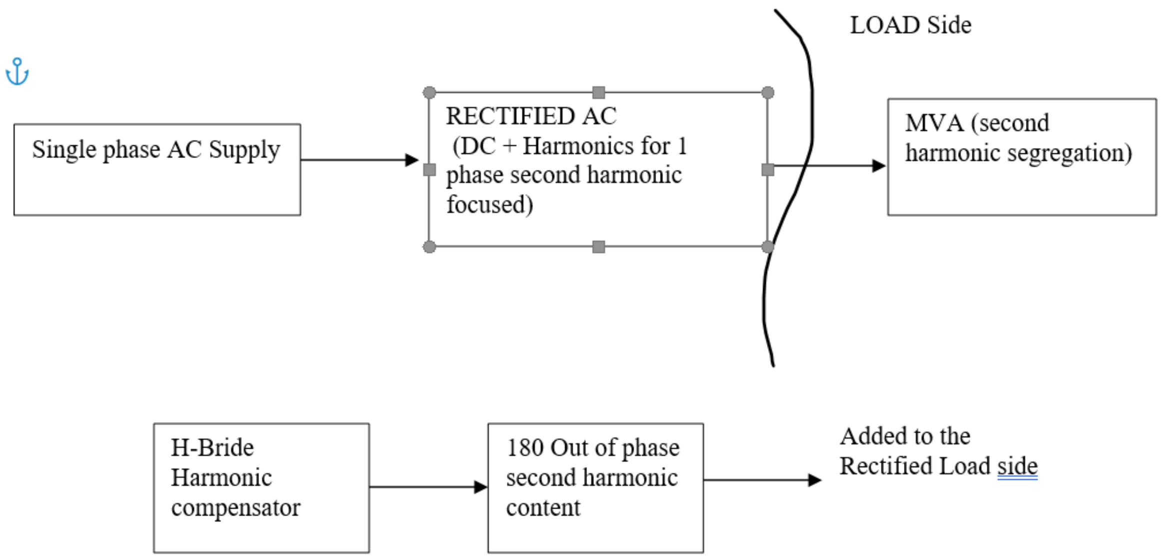


Fig 3.8 Basic Block Diagram of flow of Second harmonic injection

This technique offers a more effective solution for harmonic mitigation compared to conventional methods. The proposed methodology integrates the current injection technique with a PI controller, incorporating devices like a hysteresis current controller and a PI controller to shape the current waveform and reduce harmonics.

This system, when combined with the PI controller, enhances harmonic filtering and improves power quality.

The work is simulated for an AC-DC interconnected system using MATLAB/Simulink.

3.6 CONCLUSION

In conclusion, this chapter elucidated a comprehensive model for a single-stage AC-DC Boost Power Factor Correction (PFC) system with second harmonic mitigation employing active filters. The proposed model integrates various components including the AC-DC Boost PFC converter, harmonic compensator, and active ripple compensator.

The harmonic compensator facilitates charging a Li-ion battery under continuous current control mode, enhancing filter size reduction. Furthermore, the active ripple compensator, employing a self-balanced H-Bridge inverter, effectively mitigates the dominant second harmonic component at the DC side of the rectifier.

Additionally, the chapter discussed the control methodology involving PID controllers to enhance power loss reduction and energy efficiency. The utilization of sustainable power electronics components, particularly diodes in rectifiers, was emphasized for improving power quality in distributed generation systems.

Moreover, the incorporation of the Moving Average Filter (MAF) in the model demonstrated superior harmonic elimination performance compared to conventional Low-Pass Filters (LPF), as depicted in the Bode plot analysis. The discrete-time description of MAF was elaborated, highlighting its practical implementation in simulations.

Furthermore, the chapter delved into the control strategy of PID controllers, addressing the challenges posed by the complexity and non-linearity of current power grids. The integration of smart techniques into PID controller design was advocated for improved performance in handling modern grid technologies.

Lastly, the technique of second harmonic injection for harmonic mitigation was discussed, emphasizing its direct and computationally efficient nature. This technique, when combined with a PI controller, demonstrated enhanced harmonic filtering and improved power quality in AC-DC interconnected systems. The effectiveness of the proposed methodology was validated through simulations conducted using MATLAB/Simulink.

CHAPTER 4
SIMULATION AND RESULTS

4.1 INTRODUCTION

This chapter focuses on the simulation and results of an AC-DC Boost PFC converter integrated with second harmonic mitigation using the active filter technique, with a specific emphasis on the Moving Average Filter. Through detailed simulations and analysis, this chapter aims to provide insights into the effectiveness of employing active filtering techniques, particularly MAF, in mitigating harmonic distortions and improving power quality in AC-DC power conversion systems.

Furthermore, the simulation setup and methodology employed to evaluate the performance of the AC-DC Boost PFC converter with second harmonic mitigation using MAF are described in previous chapters in detail. Parameters such as input voltage, load conditions, and control strategies are systematically varied to assess their impact on system performance and harmonic reduction capabilities.

The chapter culminates in a comprehensive analysis of simulation results, highlighting the effectiveness of the proposed active filtering technique in mitigating harmonic distortions and improving power quality. Key performance metrics such as Total Harmonic Distortion (THD), power factor, and output voltage ripple are evaluated to assess the efficacy of the implemented solution.

Overall, this chapter serves as a valuable resource for researchers, engineers, and practitioners seeking to understand the practical implementation and performance of AC-DC Boost PFC converters with second harmonic mitigation using active filter techniques, particularly the Moving Average Filter.

4.2 AC-DC with BOOST Power Factor correction (PFC) Converter without Compensator

Parameters	Value
Input AC Voltage	230 volts rms, 50 Hz
DC Side Inductor (L_{filter})	500 µH
Output capacitance (C_1)	470 µF
L_1 and L_2	1.5 mH
Inverter capacitance (C_H)	470 µF
Output power	6.494 kW

Table 4.1

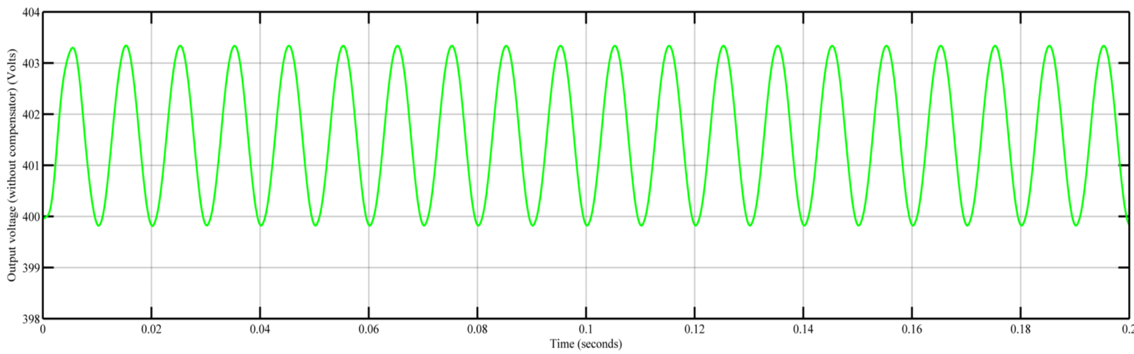


Fig 4.1 Output voltage without compensator

The above results shows that the rectified DC output has ripple content which is rich in second harmonic contents. In order to mitigate this, we use MVA and harmonic compensation methodology.

4.3 Moving Average Filter Simulation results

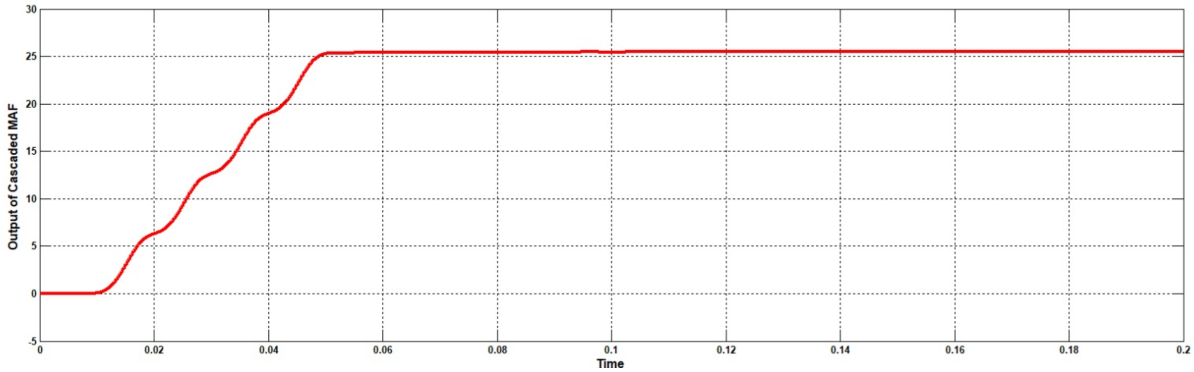


Fig 4.2 Output current from MAF

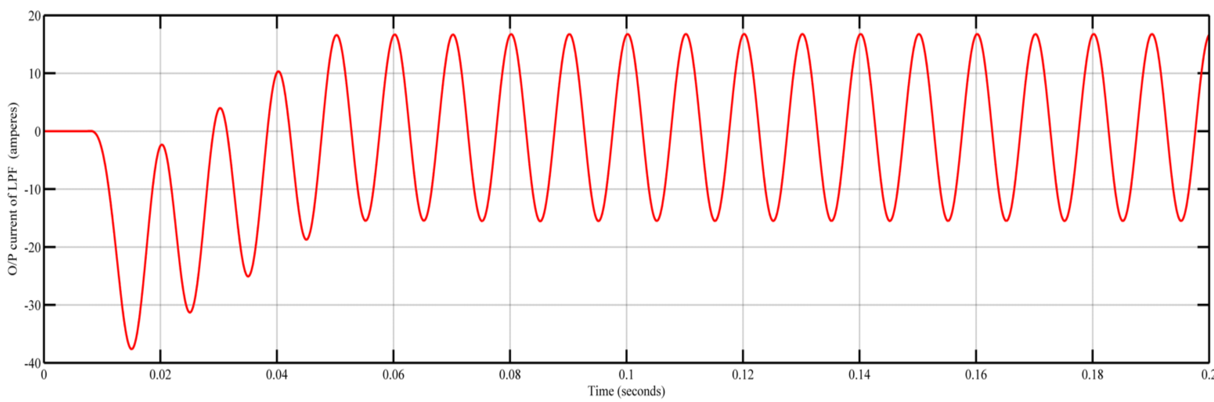


Fig 4.3 Output current waveform from cascaded LPF

From fig 4.3 it can be clearly seen that second harmonic current has been segregated from DC + harmonic contents (of rectified output)

4.4 Hysteresis Current Control

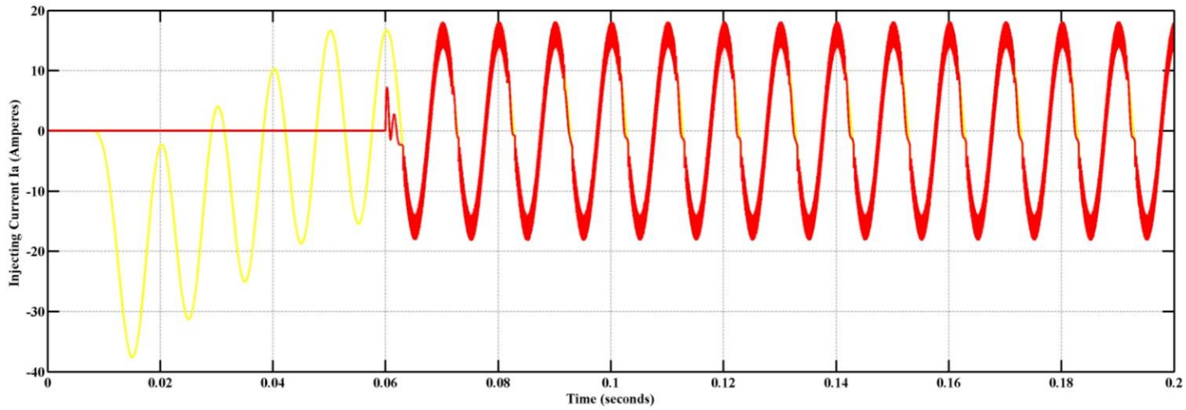


Fig 4.4 Output waveform of Hysteresis current control (yellow)

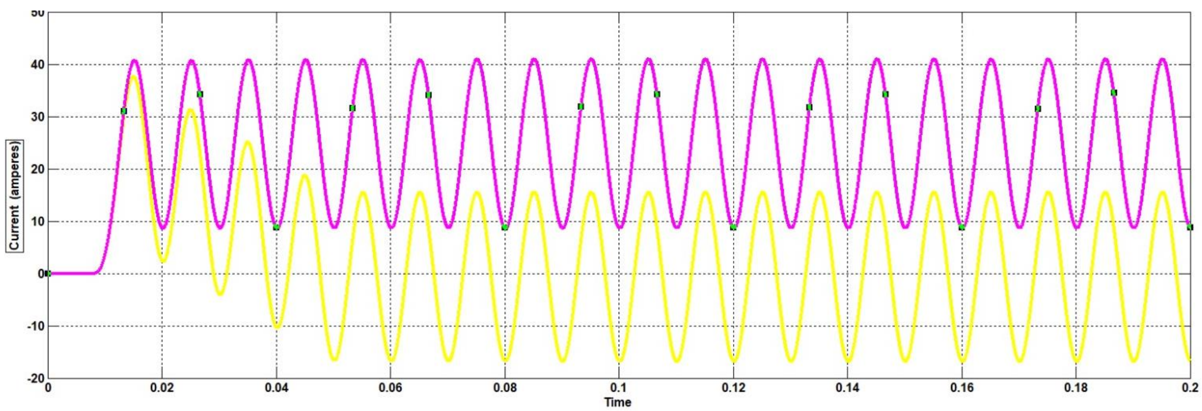


Fig 4.5 Second harmonic current waveform

4.5 Output Voltage and Output Current Waveform

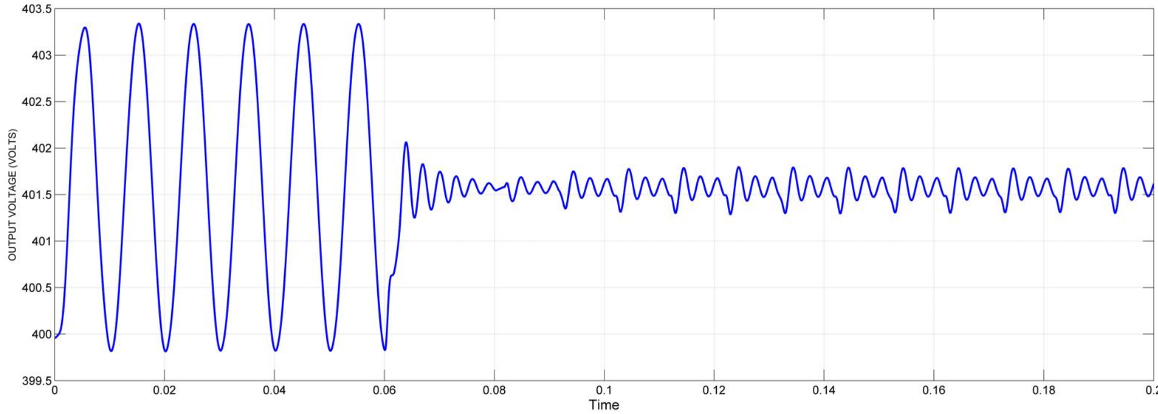


Fig 4.6 Output Voltage waveform with compensator

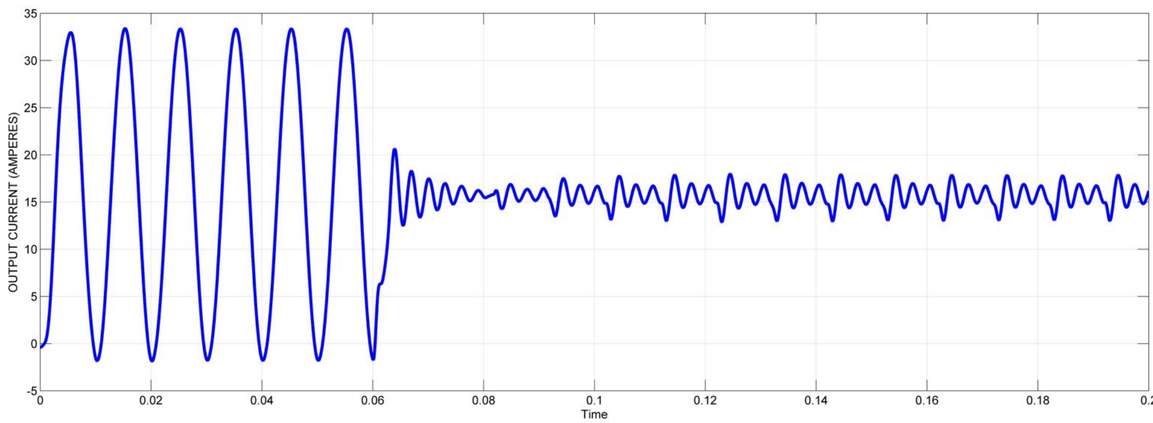


Fig 4.7 Output Current waveform with compensator

Total Harmonic Distribution (THD)

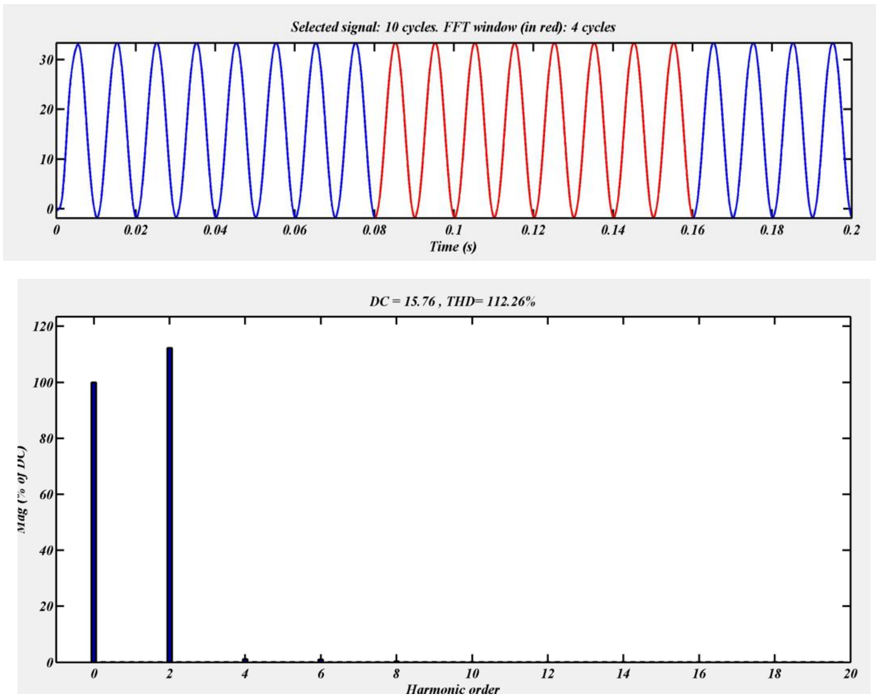


Fig 4.8 THD of the rectifier without compensator.

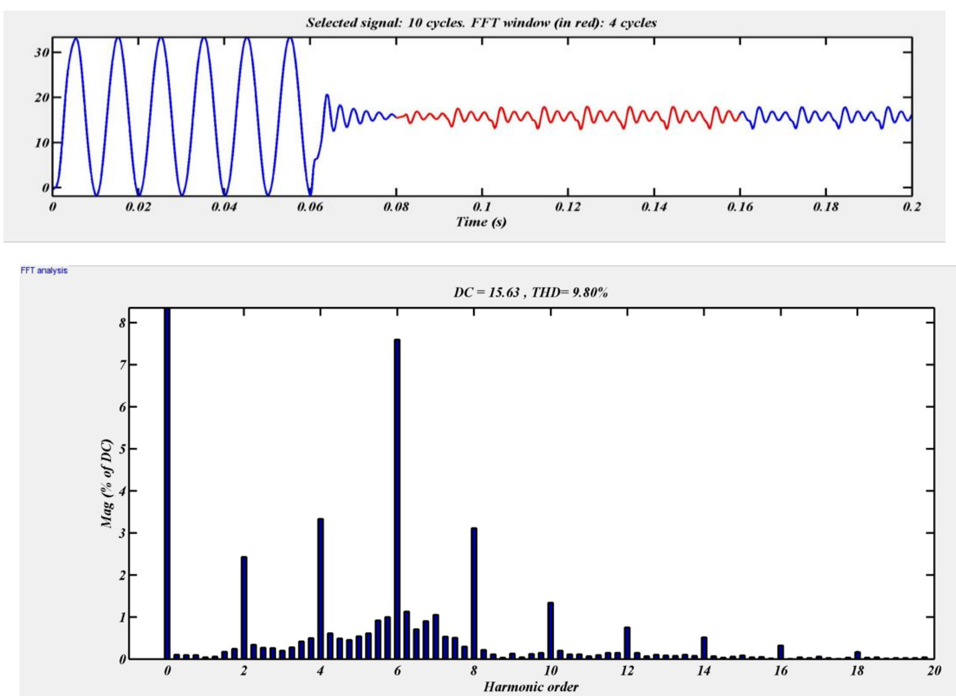


Fig 4.9 THD of the rectifier with the proposed compensator.

CONCLUSION

In conclusion, the simulation and results presented in this chapter provide valuable insights into the efficacy of employing active filter techniques, with a specific focus on the Moving Average Filter (MAF), for second harmonic mitigation in AC-DC Boost Power Factor Correction (PFC) converters.

Through a comprehensive analysis of simulation outcomes, several key findings have been elucidated. Firstly, the integration of active filtering techniques, particularly MAF, demonstrates significant potential in effectively mitigating harmonic distortions and improving power quality in AC-DC power conversion systems. The MAF, with its ability to extract second harmonic components and generate compensating currents, emerges as a promising solution for reducing harmonic content and enhancing system performance.

Moreover, the simulation results underscore the importance of proper control strategies and parameter optimization in maximizing the effectiveness of active filtering techniques. By systematically varying input voltages, load conditions, and control parameters, the impact of these factors on system performance and harmonic reduction capabilities has been thoroughly evaluated, providing valuable insights for practical implementation.

Furthermore, the analysis of key performance metrics such as Total Harmonic Distortion (THD), power factor, and output voltage ripple reaffirms the effectiveness of the proposed active filtering solution in achieving desired objectives. The simulations demonstrate notable improvements in THD reduction and power factor enhancement, indicative of the successful mitigation of harmonic distortions.

Overall, the findings presented in this chapter contribute to advancing the understanding of active filter techniques for harmonic mitigation in AC-DC Boost PFC converters, particularly with the utilization of the Moving Average Filter. By providing empirical evidence of the effectiveness of these techniques through detailed simulations and analysis, this chapter serves as a valuable resource for researchers, engineers, and practitioners in the field of power electronics, facilitating the development of more efficient and reliable power conversion systems.

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

A current control-based approach to mitigate the second-order harmonics at the DC side of the rectifier has been proposed. The simulation results validate the efficacy of this method. This approach is significantly less complex compared to traditional methods, and it can be easily implemented and programmed on microcontrollers, making it highly cost-effective. By utilizing microcontrollers, the method leverages readily available and inexpensive technology, thereby reducing the overall system cost and complexity.

The proposed method stands out for its practicality and feasibility, providing more achievable results for given specifications. Its simplicity and cost-effectiveness do not compromise its effectiveness, as it successfully maintains the desired performance levels. The low computational requirements further enhance its attractiveness, ensuring that it can be deployed in various applications without necessitating high-end processing units.

In addition to cost savings, the reduced complexity of this method facilitates easier implementation and maintenance. This is particularly beneficial for large-scale deployment in electric vehicle (EV) charging systems, where efficiency and reliability are paramount. The proposed approach also aligns well with the trend towards more intelligent and adaptive power electronic systems, capable of responding dynamically to changing load and supply conditions. Overall, the proposed current control-based method provides a viable and efficient solution for mitigating second-order harmonics in rectifier systems, particularly in the context of EV battery charging. Its validation through simulation confirms its potential for real-world applications, making it a valuable addition to the field of power electronics. Future work may focus on further optimization and real-world testing to fully harness its capabilities.

5.2 FUTURE SCOPE

The current control-based approach for mitigating second-order harmonics in onboard EV charging systems offers significant potential for future research and development. Building on its demonstrated simplicity, cost-effectiveness, and compatibility with microcontrollers, this method can be further refined and expanded.

Future research could explore integration with advanced microcontroller and DSP technologies, enhancing scalability for higher power systems and conducting real-world testing to validate the method under diverse conditions. Additionally, integrating this technique with renewable energy sources and developing hybrid control strategies could improve overall system efficiency and flexibility. Advancements in control algorithms, incorporating machine learning for real-time harmonic management, and long-term reliability studies will provide deeper insights into maintenance and system longevity. Establishing industry standards and compliance will facilitate broader adoption and commercialization, ensuring the technique meets regulatory and safety requirements.

By addressing these areas, future research can significantly enhance the effectiveness, reliability, and applicability of current control-based harmonic mitigation in EV charging systems, advancing the field of power electronics, and supporting the transition to electric vehicles.

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