"IMPLEMENTATION OF ACTIVE INTERPHASE TRANSFORMER IN 12-PULSE CONVERTER & GETTING THE PERFORMANCE LIKE 24-PULSE CONVERTER"

By

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(12MEEP42)

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

May 2014

"IMPLEMENTATION OF ACTIVE INTERPHASE TRANSFORMER IN 12-PULSE CONVERTER & GETTING THE PERFORMANCE LIKE 24-PULSE CONVERTER"

Major Project Report

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Power Electronics, Machines and Drives)

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May 2014

Undertaking for Originality of the Work

I **Milan Anandpara**, Roll No. **12MEEP42**, give undertaking that the Major Project entitled **"IMPLEMENTATION OF ACTIVE INTERPHASE TRANSFORMER IN 12-PULSE CONVERTER & GETTING THE PERFORMANCE LIKE 24-PULSE CONVERTER"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Power Electronics Machines** & **Drives, Electrical Engineering**, under Institute of Technology of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

....

Signature of Student

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Certificate

This is to certify that the Major Project Report entitled **"Implementation of Active Interphase Transformer in 12-pulse converter & Getting the Performance Like 24-Pulse Converter"** submitted by **Mr. Milan Anandpara** (**Roll No.: 12MEEP42**) towards the partial fulfillment of the requirements for Master of Technology (Electrical Engineering) in the field of Power Electronics, Machines & Drives of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

Harmonics is one of the most severe problems in variable frequency drives. Harmonics are generated due to switching action of the power electronics converters, which are known as non-linear loads. Variable frequency drives are made up of two power sections, a rectifier section and an inverter section. The six pulse diode bridge rectifier is most widely used as an AC-to-DC converter. But major disadvantage of diode bridge rectifier is that it will distort utility line current. To minimize the harmonics we place the filter which increases the cost, size & volume. To mitigate harmonics from utility line currents interphase reactor is implemented for paralleling of converters. It ensures equal sharing of current among the parallel connected converters. There are two type of interphase transformer uncontrolled & controlled (Active IPT). Here a new active interphase transformer (controlled) for 12-pulse diode bridge rectifier with reduced kVA is implemeted. This system draws near sinusoidal currents from the utility. Simulations are done for 2 schemes. In scheme I low kVA PWM VSI injects triangualr shaoed current into the secondary of Active interphase reactor of a 12-pulse diode bridge rectifier. This modification result in near sinusoidal utility line currents with less than 1% THD. In scheme II Boost Power Factor Controller circuit connected across auxiliary winding of Active IPT to meet IEEE-519 harmonic current limit. This system is very rugged and in the event active control fails this system will revert to 12-pulse operation with 5^{th}&7^{th} harmonics cancellation. Simulation & Experimental results are provided for 50 kVA, 415 V 12-pulse rectifier system with an autotransformer arrangement. The resulting system draws clean power from the utility & is suitable for powering larger kVA ac motor drive system.

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Nomenclature

V_s .... Supply Voltage

I_s .... Supply Current

n .... turns ratio of Autotransformer

L_{s1}, L_{s2} .... Ac Line Reactance

V_x .... Secondary side voltage of Active IPT

V_m .... Primary side voltage of Active IPT

I_x .... Injected current into auxilliary winding of Active IPT

N_x .... No. of turns of auxilliary winding of Active IPT

N_m .... No. of turns of Primary winding of Active IPT

V_0 .... Load Voltage

I_0 .... Load Current

I_{d1} .... Output Current from Rectifier-1

I_{d2} .... Output Current from Rectifier-2

V_{d1} .... Output Voltage from Rectifier-1

V_{d2} .... Output Voltage from Rectifier-2

L_1 .... Magnetizing Inductance of IPT

K_1 .... Percentage ripple of load current I_0

c .... Filter Capacitor

R .... Load Resistance

Contents

Chapter 1

Overview Of Interphase Transformer

1.1 Introduction

Large harmonics, poor power factor & high total harmonics distortion in the utility interface are the common problem when non-linear loads such as adjustable speed drive, power supplies, induction heating system, ups system, aircraft converter system, are connected to the electrical utility. Due to non-linear nature of the load, input line current have significant harmonics. The non-sinusoidal shape of the input current drawn by the rectifiers causes a number of problems in the sensitive electronic equipment and in power distribution network. The distorted input current flowing through the sysytem produces distorted voltages at the point of common coupling.[3][10]

To obtain dc power 3-phase rectifiers are used which cause distortion in the supply current (high %THD) which can lead to malfunction of other sensitive electronic equipment.To overcome these harmonics problem filters are widely used. It may be active, passive or hybrid type depending on the economic consideration and the system power rating. Sometimes these are close to converter rating. It increases cost, amount of component & size of the system resulting in lower reliability of the system.

Multi pulse methods are very popular in the power electronics industry, because of its simplicity, reliability and high performance in improving the power quality. 12-pulse operation can be obtained by connecting two 3-phase 6 pulse bridge rectifier either in series or in parallel. The operation of the conventional 12-pulse diode bridge rectifier result in the cancellation of the 5^{th}&7^{th} harmonics in the input utility line currents. To increase number of pulses (18 or 24 pulse operation) additional diode bridge rectifiers along with complicated multiphase transformer arrangement become necessary, which adds the cost & complexity.[3]

By connecting bridge rectifier in parallel high current operation can be obtained. To make sure equal sharing of current interphase transformer (IPT) is required. If parallel operation is carried out without incorporating IPT, one device will carry high current as compare to other. It will damage the damage that electronic device & other component in the system. % THD in the utility line current can also be reduced by incorporating IPT. The term interphase reactor, spanning reactor & current balancing transformer have also been applied to describe this device.

There are basically 2 types of IPT (i) Uncontrolled (Conventional IPT) & (ii) Controlled (Active IPT). The active IPT (controlled IPT) has the best effect on harmonic component reduction in utility input current (THD less than %1). In this project new active interphase reactor for 12-pulse diode bridge rectifier is proposed. The proposed system draws near sinusoidal current from the utility. In this scheme a low kVA active current source inject a triangular current into an interphase reactor of a 12-pulse diode rectifier. This modification results in near sinusoidal utility line current with less than 1% THD. This 12-pulse diode bridge rectifier has lower kVA magnetics & fewer component count.

1.2 Scope of work

Simulations & Experiments are done for 50 kVA, 415 V autotransformer based 12-pulse rectifier system. Two possible way for implementation of active interphase transformer and are called Scheme I & Scheme II. an autotransformer is employed to obtain 30^0 phase shift between two diode bridge rectifiers. In Scheme I full bridge invertre injects triangular shaped current into auxiliary winding of active interphase transformer. This modofication results in near sinusoidal line currents from utility. In scheme II Boost Power Factor Controller circuit is connected across auxiliary winding of active interphase transformer which draw triangular shaped current. Hardware is model for 50 kVA 415 V 12-pulse rectifier system with boost power factor controller circuit to meet IEEE-519 harmonic current limit.

Chapter 2

Interphase transformer

2.1 Conventional 1-phase IPT (uncontrolled)

Magnetic devices are commonly used to associate 3-phase voltage source converter (VSC) in order to increase the converter overall power rate. The magnetic elements are efficient and robust but they have disadvantage of the volume, weight and cost. These three characteristics are related to the VA rating the magnetic device.

The VA rating of the magnetic device for serialize VSCs is much higher than the VA rating of a magnetic device needed to parallelize VSCs. That is why inductor is a suitable solution to connect more than one power electronics converter in parallel. If decoupled inductors are used to parallelize VSCs, the output current of each VSC must be controlled to assure that current is equally shared among the converters. If the coupled inductors are used, then the current is equally shared among the converters because of the coupled inductors. These inductors are known as interphase transformer or reactor.[6]

In the single phase IPT two windings wound on a same core. Interphase transformer functions to support ac voltage differences existing between converter outputs & allows the converters to act as if they are operating alone. However they cannot help balance steady-state differences in dc voltage. They support instantaneous

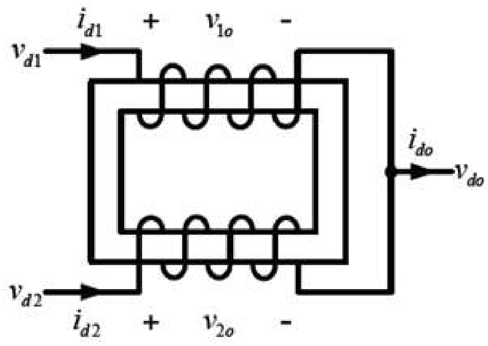

Figure 2.1: IPT basic configuration with U type magnetic core

(i.e.ac) voltage differences but not average (i.e.dc) voltage difference. The windings carry both dc and ac currents. Connections are made in such a way that dc currents, flowing to the load, cause opposing ampere-turns on the core. There is no inherent restriction on the no. of windings or converters that may be paralleled, provided that the magnetic core has an appropriate no. of limbs.

The coupled inductors (IPT) allows to associate converters & increase the converter output power with increasing relatively low weight, cost & volume of the overall converter. By using IPT the current is inherently shared by each parallelize converter leg.

Fig. 2.1 shows the basic configuration of the an IPT by using U type magnetic core. It consists of magnetic core with two windings where the ends of them are connected to each other forming the output terminal of the IPT. The magnetic flux through the magnetic core is only the difference between the currents i_{d1}&i_{d2}.

The instantaneous value of the currents i_{d1}&i_{d2} tends to be same because IPT impose a high impedance to their difference. The current that flows through each winding of the IPT, generates a magnetic force in opposition to each other. Therefore when both the currents are equal, no flux is generated through the magnetic core.[6]

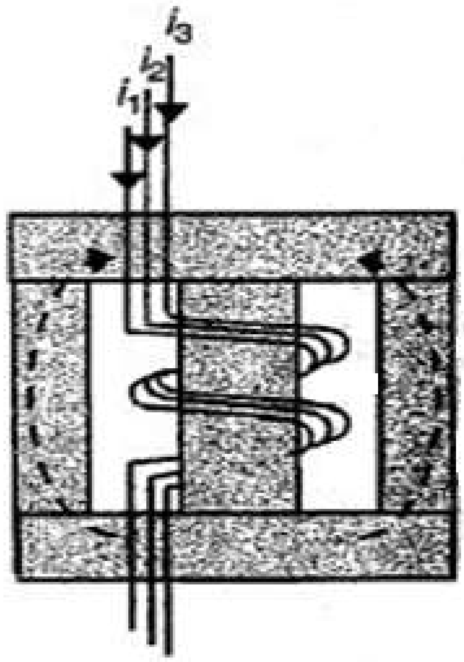

Figure 2.2: 1-phase shell type construction on zero-sequence fluxes

kVA rating of IPT is found out by the equation written below.

kVA rating of the IPT $= 0.5(\Sigma V_{winding} * I_{winding})$

A single phase shell structure can be used. The advantage of shell mechanical construction (shown in fig. 2.2) is that the winding on the interphase transformer can be trifilar wound and placed on the central limb. This gives excellent coupling.[1]

2.2 3-phase Interphase Transformer

Fig. 2.3 shows how the three converters are paralleled by 3-phase Interphase Transformer. When the current are balanced, there are no net dc ampere-turns acting directly around the flux loops. Unbalance currents can cause substantial dc flux. The total flux must not be so high as to cause saturation of the iron core.[1]

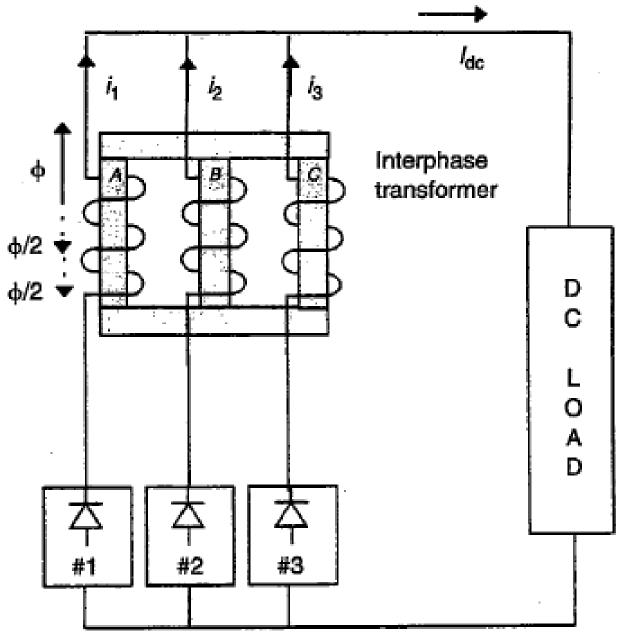

Figure 2.3: IPT for three converters

2.3 Effect of interphase transformer saturation

Any saturation in the interphase transformer will detract from the design performance; however this is more critical in some circuits than others. In conventional 12-pulse system isolation is provided by the Y-Y & Y-Δ connected transformer & the system shown in fig. 3.4, in these systems the interphase transformer is not essential to secure 12-pulse operation. Rather it is mean to secure the desirable features of each converter acting alone, for example a 120^0 degree device conduction.

Without an interphase transformer in fig. 3.4 or if it is saturated, the rectifier conduction angle will neglect ac line reactance, change from that of a single 120^0 pulse to two 30^0 pulses. A 12-pulse system in phase shift is provided by the autotransformer (without isolation) interphase transformer is essential for 120^0 pulse operation. This is a disadvantage & requires even more careful control of the design.[1]

Chapter 3

Parallel operation of 6-pulse rectifiers by IPT

3.1 DC & AC condition in parallel operation of DC & AC voltage source

A major design goal in multipulse operation is to get the converters or converter semiconductor devices, to share current equally. If this is achieved, then maximum power & minimum harmonic currents can be obtained.

To make successful parallel operation, we have to consider ac & dc condition. Also, the circuit connections are important if unwanted conduction paths are possible. Fig. - 3.1 & Fig. - 3.2 show how the currents in parallel circuits are shared. The power sources are effectively isolated such that there are no alternative unwanted conduction paths.

Fig.3.1 show two batteries in parallel, feeding a common load. This figure is used to illustrate the effect of dc unbalance. For i_1&i_2 to be equal, we need E_1&E_2 to have the same amplitude and resistors r_1&r_2 to be equal. If E_1&E_2 are not equal, then appropriate values of r_1&r_2 can be chosen to give equal currents under a given load condition. [1]

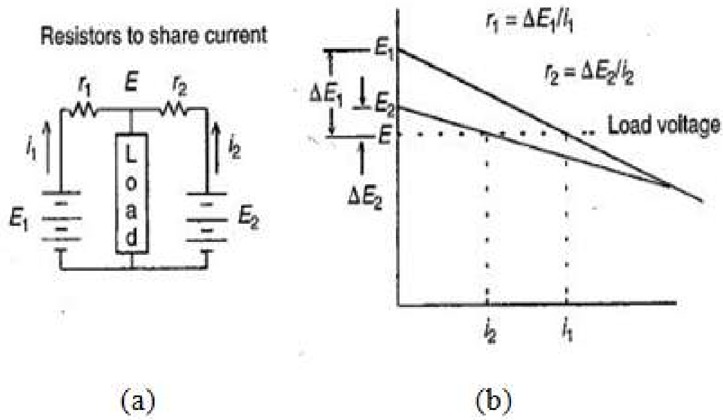

Figure 3.1: (a) Paralleling DC voltage source (b) voltage regulation diagram

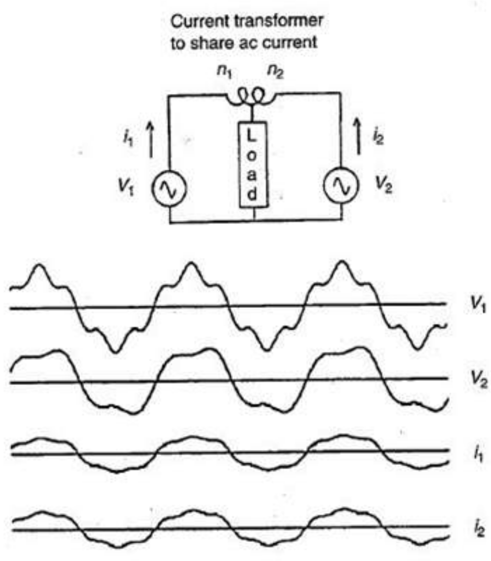

Figure 3.2: paralleling ac voltage source, Waveform for $n_1 = n_2$ & resistive load

Fig. 3.2 shows 2 ac voltage sources in parallel. Just as resistance does in dc circuits, ac sources can have impedance to share the load currents. However, by joining the circuits through a tapped current transformer, powerful method of controlling current balance is possible. If turns $n_1 \& n_2$ are equal, then current $i_1 \& i_2$ will be equal be equal, consideration is that CT is designed with the ability to supply the compensating voltage. The transformer plays the active role by developing a voltage to correct for any unbalance caused by source voltage or impedance variation.[1]

3.2 Combining two rectifiers by IPT

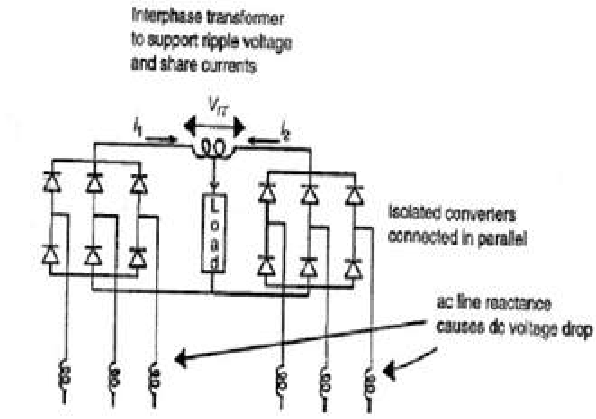

Figure 3.3: paralleling of two rectifiers by single phase IPT

Each converter includes an ac o/p voltage ripple, which is a natural part of the power conversion process. This ripple is affected by ac line reactance & by phase control. If these voltage differences are not supported in some way, the device conduction pattern will be changed, and each converter will interfere with the operation of the other. To prevent this interfering effect, an interphase transformer is interposed between the two converters.

Ac line reactance causes a voltage drop at the dc output in each circuit, just as resistor do in the case of paralleled batteries but without attendant power dissipation.

If the system voltage drop is 3%, then assuming that each converter must not exceed its current rating, a 1% difference in converter dc voltage would result in one converter supplying 50% more current than the other.

The ac voltage ripple existing between the converters can be calculated from the specific converter output waveform, but the effect of commutating reactance & any phase control must be considered. If the converter currents are evenly shared, the transformer need to be rated only for 50% of the effective kVA supported; however, without means to ensure proper current sharing, the rating may easily be 75% of the power. Ac line reactance should be 1.8%. It is used to balance dc output voltage.[1]

3.3 Parallel operation of 12-pulse rectifier by half kVA Δ-Y transformer

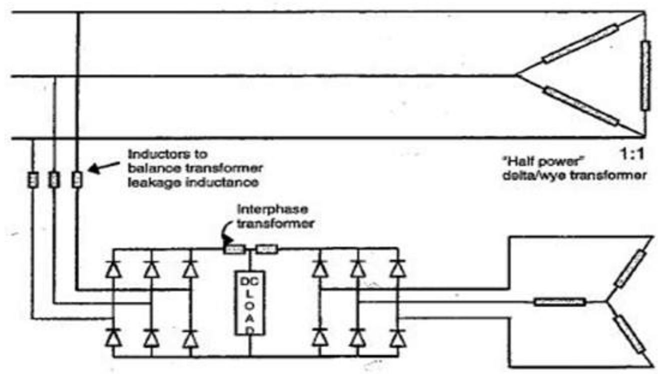

Figure 3.4: interphase transformer to support ripple between two parallel rectifier

In this scheme kVA rating of the interphase is lesser than kVA rating of the interphase transformer when paralleling by means of autotransformer. Only 1 interphase transformer is required. Here kVA rating of the transformer is half as compared to KVA rating of transformer (Y-Y & Y-Δ) in conventional 12-pulse converter. kVA rating of transformer = $0.52P_0(PU)$

3.4 Parallel operation of 12-pulse rectifier when phase shift by means of an Autotransformer (differential delta transformer)

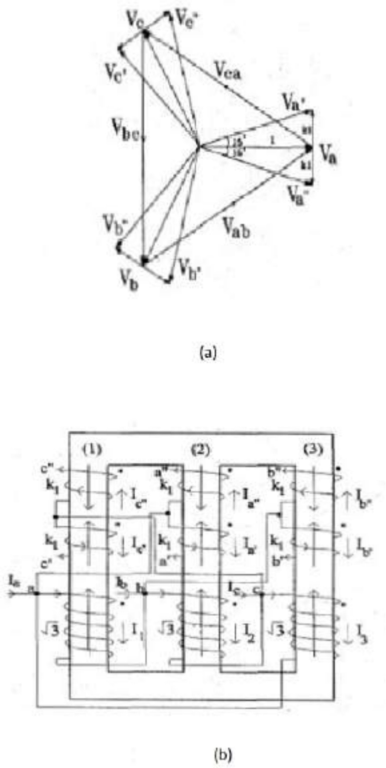

Figure 3.5: (a) vector diagram of the delta-type autotransformer connection (b) autotransformer winding on a three limb core

To obtain adequate operation of the 12-pulse converter, there must be a 30^0 phase shift between the supplies of both converters. If the 30^0 phase shift, appropriate to 12-pulse performance, is obtained using a polygon transformer (autotransformer), as shown in fig. 3.5 the transformer rating will be only 22% of the total dc output power. Fig. 3.5 shows the topology in which a differential delta transformer (delta connected autotransformer) is used to provide the phase shift of $\pm 15^0$ in 12-pulse converter.[1]

$$MinimumPhaseShift^0 = \frac{60}{no.ofConverter}$$

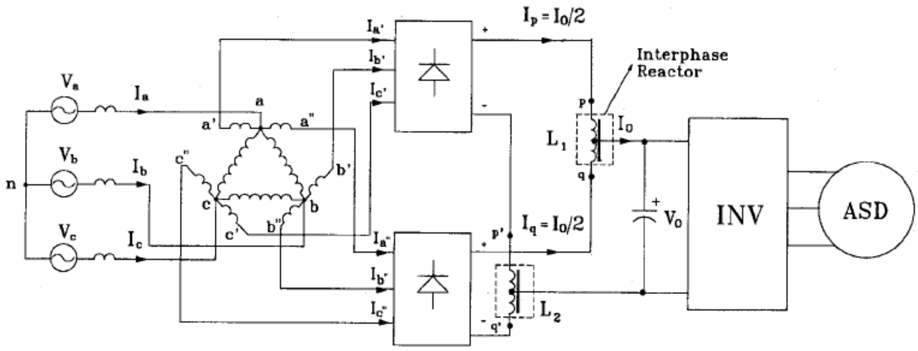

Figure 3.6: 12-pulse rectifier employing delta connected autotransformer

To obtain 12-pulse result from the circuit shown in fig. 3.6, two interphase transformers are essential. One interphase transformer is connected in the positive output, and one is connected in the negative output. These interphase transformer isolate unwanted conduction paths & allow the converters to operate practically independently because the autotransformer does not provide isolation, the voltage to be supported across the interphase transformer is much greater. Each interphase transformer is larger than the single unit of interphase transformer in conventional Y-Y & Y-Δ connected 12-pulse converter. If the interphase transformers are not incorporated in fig. 3.6 or significant saturation occurs, it will not give 12-pulse operation because the absence of isolation. Because of these zero sequence harmonics comes into the rectifier input, it will distort the input line currents. That is the major disadvantage of the parallel operation by autotransformer.[1]

The purpose of the IPT is :

• To offer high impedance to cross conduction paths between the diodes in rectifier I & II.

• Offer low impedance and promote independent operation of rectifier bridge I & II in a parallel connected nonisolated 12-pulse rectifier system.

Equivalent kVA rating of the autotransformer is found out from,

$$kVA_{total} = 0.5[6|\grave{I}a||\grave{V}aa| + 3|I1||Vab|] \tag{3.1}$$

$$kVA_{total} = 0.2V_0I_0 \tag{3.2}$$

The size of the autotransformer is reduced by 80% as compared to transformers (Y-Y & Y-Δ) used in conventional 12-pulse system. The design of autotransformer is similar to the design of 3-phase core type transformer but only transformer ratio will differ. Here Delta connected autotransformer is only used to get the phase shifts.

3.5 Autotransformer turns ratio calculation

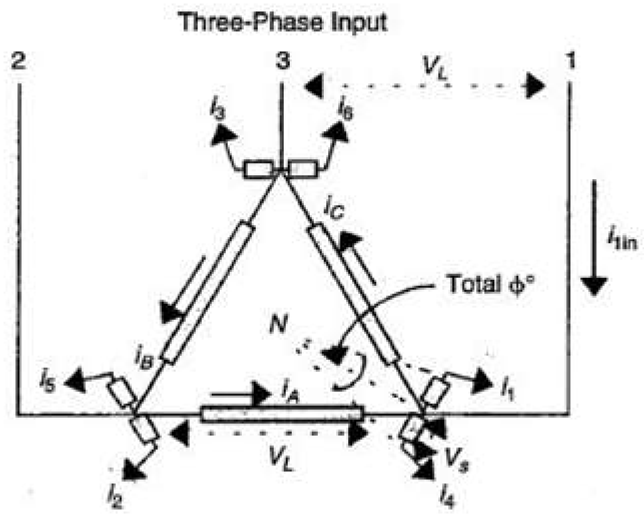

Figure 3.7: differential-delta phase splitting transformer, giving$\phi/2$ phase shift

$$n = \frac{\sqrt{3}}{tan(\phi/2)}$$
$$n = 6.47$$

Transformer ratings & no. of interphase transformer required in different schemes of paralleling 12-pulse converter,

Type	kVA rating of transformer	Harmaonics elimination	No. of inter-pahse reactor
Conventional 12-pulse (Y-Y and Y-Δ)	$1.0306V_oI_o$	5,7^{th}	1
Autoransforme based 12-pulse	$0.2V_oI_o$	5,7^{th}	2
Reduced kVA(only one transformer Δ-Y)	$0.52V_oI_o$	5,7,11,13^{th}	1

Table I: rating of transformer & no. of interphase reactor for different scheme

Chapter 4

Active Interphase Transformer

4.1 Different schemes to implement active interphase transformer

This project proposes a new 3-phase diode rectifier system which draws near sinusoidal input currents from the three phase electric utility. Simulation Results are provided for two schems. In scheme I low kVA PWM VSI injects a triangular current into an interphase reactor of a 12-pulse diode rectifier. This modification results in near sinusoidal utility line currents with less than 1% THD. In scheme II boost PFC converter circuit is connected across auxiliary winding of Active IPT to meet IEEE-519 harmonic current limit The voltampere rating of the boost PFC converter is $0.05P_0$ pu.

4.1.1 12-pulse rectifier with half power Δ-Y transformer & Active IPT

Fig. 4.1 shows the Δ-Y transformer of $0.52P_0(PU)$ is employed to get 30^0 phase shift. The interphase reactor & line impedances Ls1 & Ls2 are designed such that stable 12-pulse operation is obtained with equal current sharing. A low kVA PWM

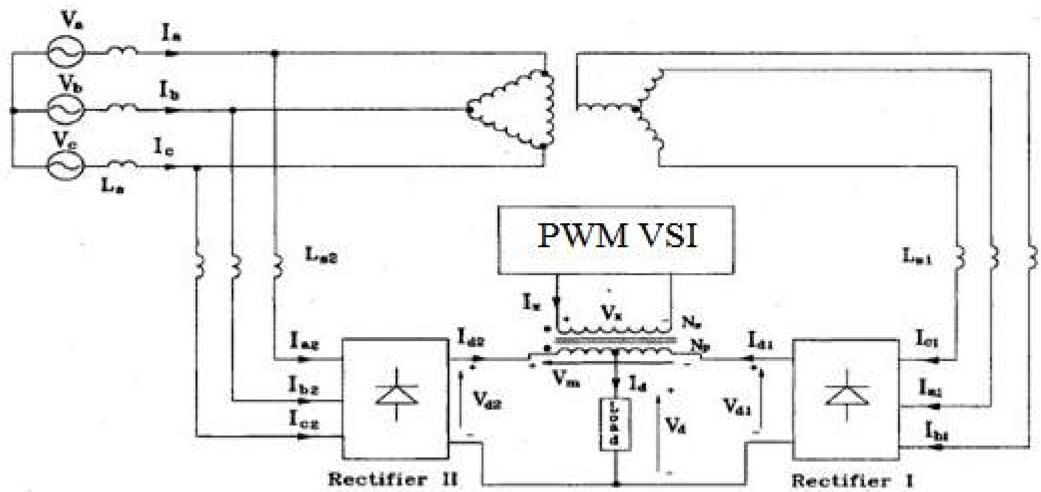

Figure 4.1: circuit diagram of half power Δ-Y transformer used for parallel operation of two diode bridge rectifier with active IPT

controlled active current source, Ix is now injected into the secondary winding of the interphase reactor. An active current source Ix is triangular in shape. By injecting triangular shaped current Ix into the secondary winding of the interphase reactor, near sinusoidal current with less than 1% THD flow from utility.[3]

The proposed scheme has the following advantages:

1 A low kVA triangular current injected into the secondary winding of the interphase reactor results in less than 1% THD in utility line currents satisfying clean power requirements.

2 The active current source can be configured with low cost high current & low voltage single phase half/full bridge MOSFET devices.

3 The active current source electronics (MOSFETs) located at the secondary of the interphase reactor is not subjected to utility line disturbances, hence the scheme is rugged.

4 In the event the active current source malfunctions, the elimination of 5th & 7th harmonics is still guaranteed due to 12-pulse operation.[3]

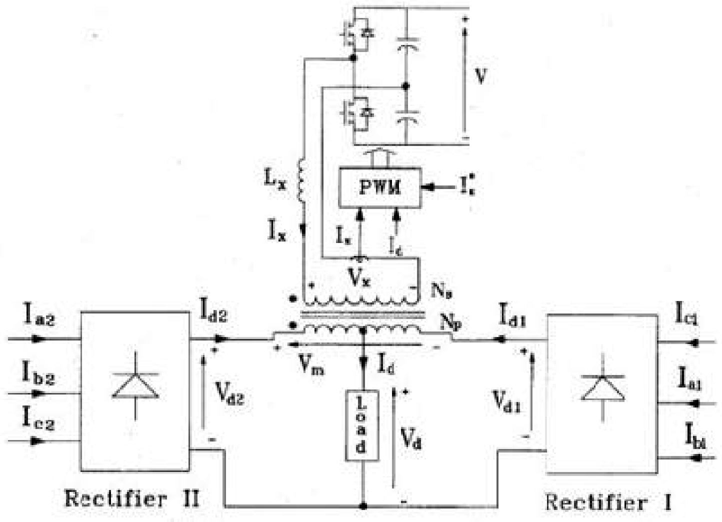

Figure 4.2: circuit diagram for implementation of active IPT

In conventional 12-pulse converter (Y-Y & Y-Δ transformer) an active IPT implemented in the same way as we have implemented in half power Δ -Y transformer as shown in fig. 4.2.

The kVA rating of the injected current source Ix is a small percentage of the output power. This demonstrates the superior features of the proposed scheme.

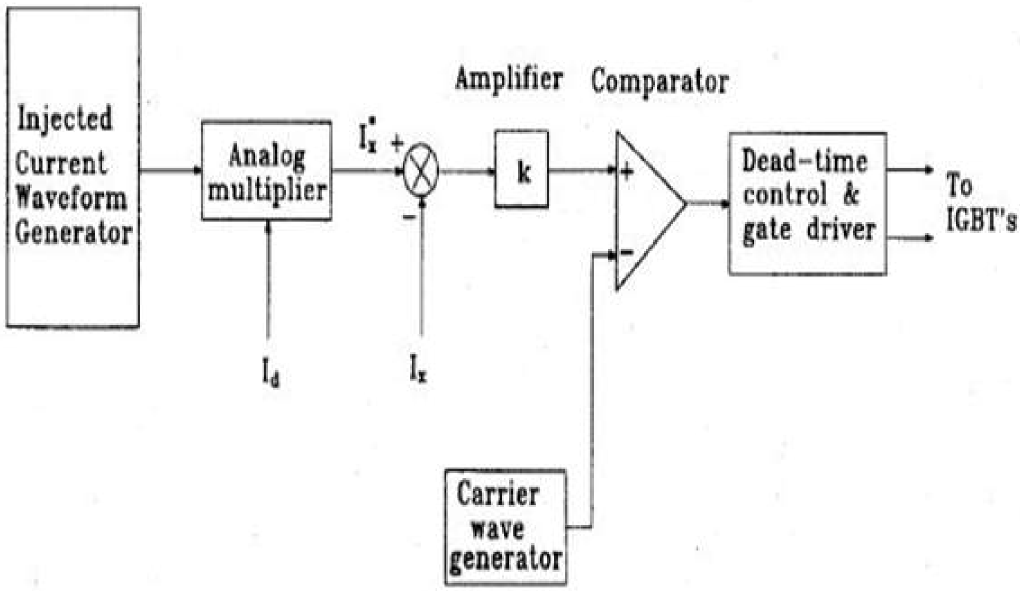

Figure 4.3: block diagram of the current-controlled PWM gating signal generator

4.1.2 Parallel operation of 12-pulse rectifier with autotransformer & Active Interphase Transformer

In this 2 IPTs are required because of absence of isolation. In this volyage to be supported across the interphase transformer is much greater. kVA rating of each IPT is higher than the single unit of IPT in case of conventional Y-Y & Y-Δ connected 12-pulse rectifier.

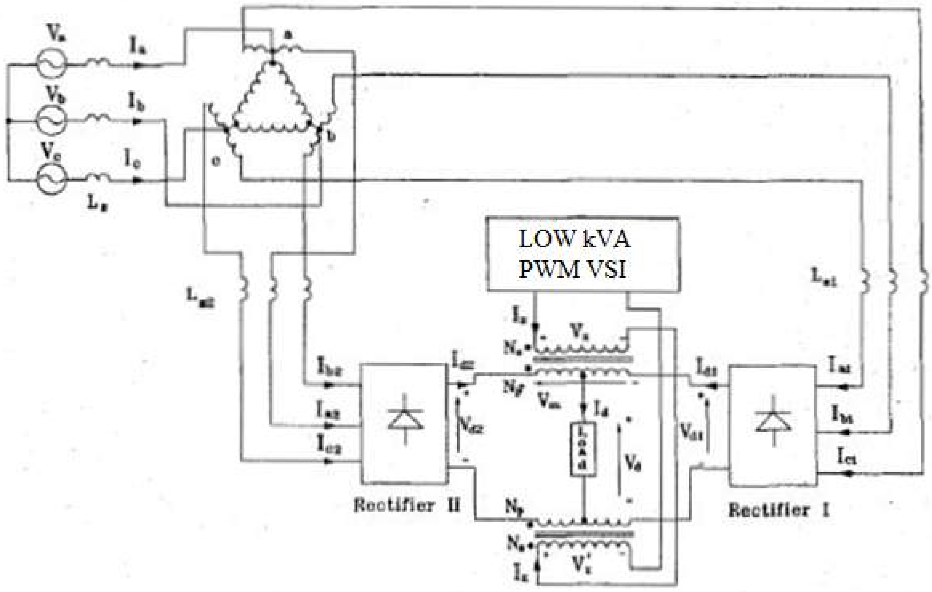

Figure 4.4: circuit diagram of 12-pulse rectifier system with autotranformer & Active IPT arrangement

4.1.3 12-pulse rectifier with Boost PFC Conerter & Active IPT

Single-phase boost PFC Coverter is connected across auxiliary winding of Active IPT. The boost converter output is fed back to the dc link. The boost converter is controlled control circuit such as by ON Semiconductors MC34262. The auxiliary winding current I_x in the Active IPT is then shown to alter the shape of the utility input current I_a to a near sinusoidal current shape. The kVA rating of boost converter is $0.05P_0$ pu.

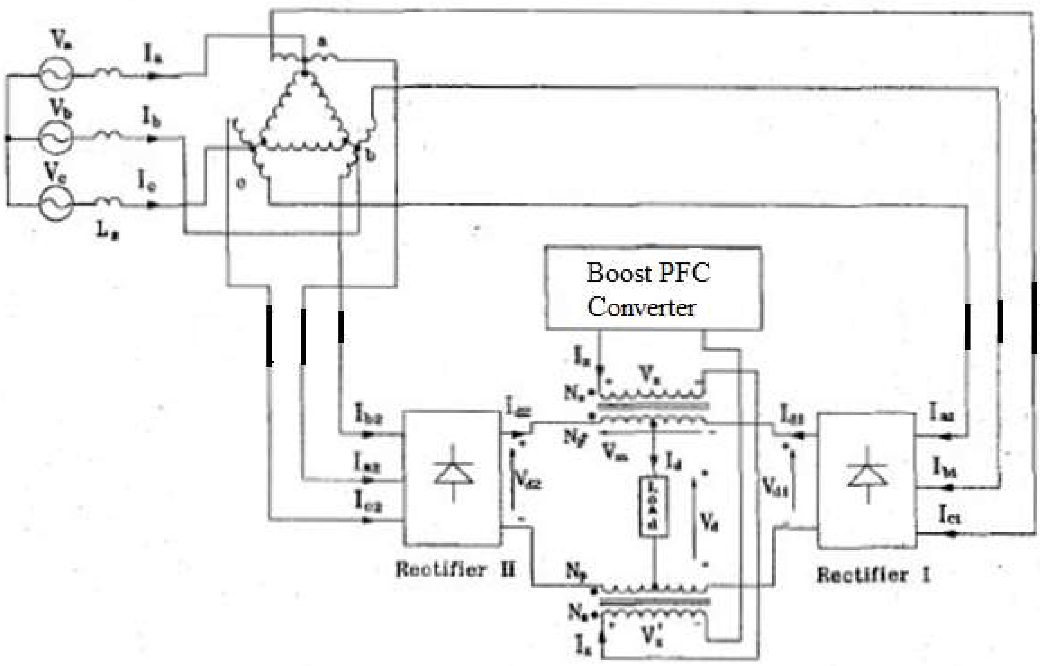

Figure 4.5: circuit diagram of 12-pulse rectifier system with boost PFC converter connected across Active IPT

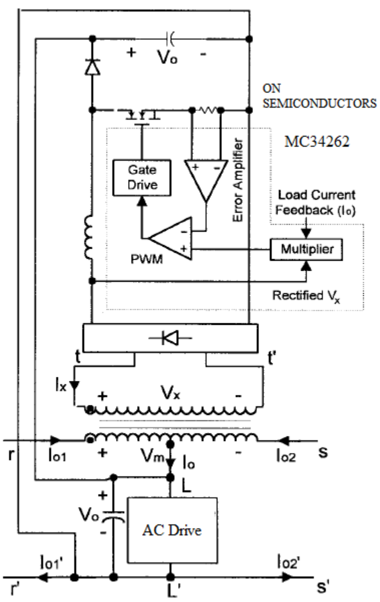

Figure 4.6: Implementation of boost PFC Converter across Active IPT

Chapter 5

MC34262- PowerFactor Controller IC

The MC34262 are active power factor controllers specifically designrd for use as a preconverter in electronic ballast and in off-line power converter applications. These integrated circuits feature an internal startup timer for stand-alone applications, a one quadrant mutiplier for near unity power factor, zero current detector to ensure critical conduction operation, transconductance error amplifier, quickstart circuit for enhanced startup, trimmed internal bandgap reference, current sensing comparator, and a totem pole output ideally suited for driveng power MOSFET.

Also included are protective features consisting of an overvoltage comparator to eliminate runaway output voltage due to load removal, input undervoltage lockout with hysteresis, cyclebycycle current limiting, multiplier output clamp that limits maximum peak switch current, an RS latch for single pulse metering, and a drive output high state clamp for MOSFET gate protection.

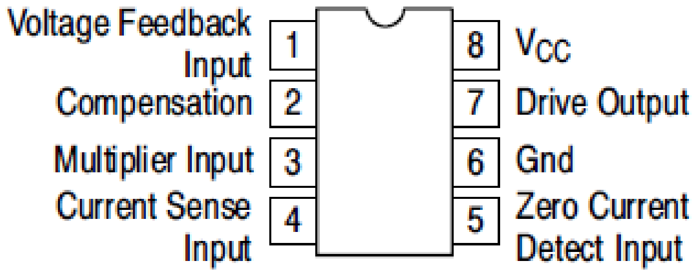

Figure 5.1: Pin Connections of MC34262

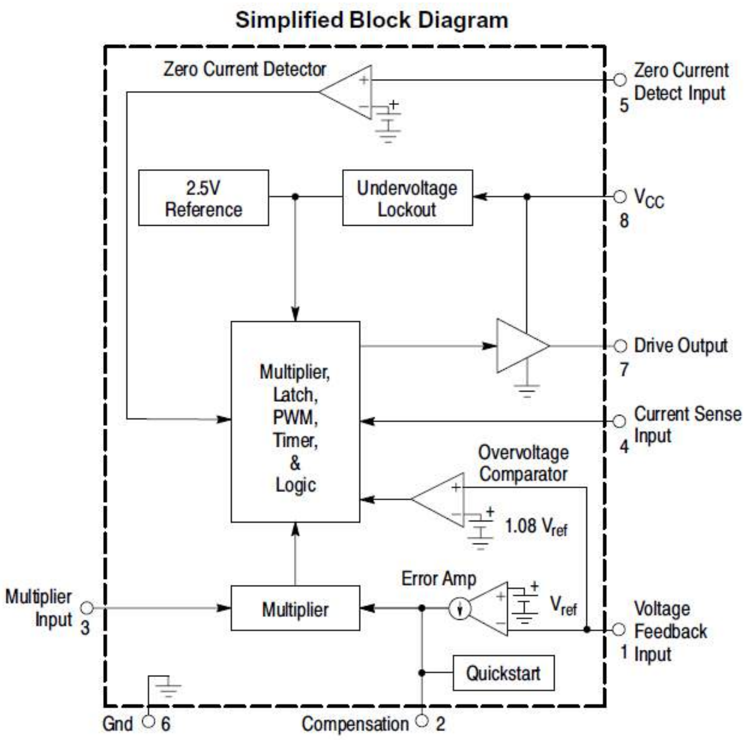

Figure 5.2: Simplified block diagram of MC34262

5.1 Functional Description

The simple rectifier circuit draws power from the line when the instantaneous ac voltage exceeds the capacitor voltage. This occurs near line voltage peak and result in a high charge current spike as shown in Fig. 5.4. Since power is only taken near the line voltage peaks, resulting spikes of current are extremely nonsinusoidal with a high content of harmonics. this result in poor power factor condition.

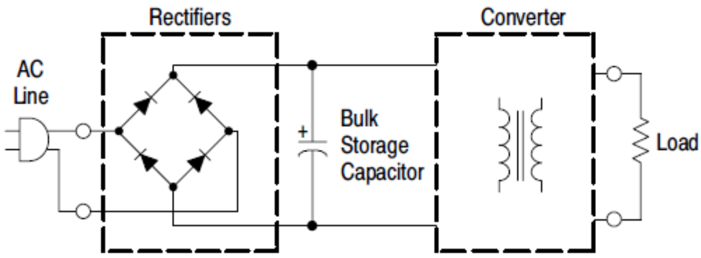

Figure 5.3: Uncorrcted power factor circuit

Power factor correction can be achieved with the use of either a passive or an active input circuit. Passive circuits usually contain a combination of large capacitors, inductors, and rectifiers that operate at the ac line frequency. Active circuits incorporate some form of a high frequency switching converter for the power processing, with the boost converter being the most popular topology, Fig. 5.5. Since active input circuits operate at a frequency much higher than that of the ac line, they are smaller, lighter in weight, and more efficient than a passive circuit that yields similar results. With proper control of the preconverter, almost any complex load can be made to appear resistive to the ac line, thus significantly reducing the harmonic current content.

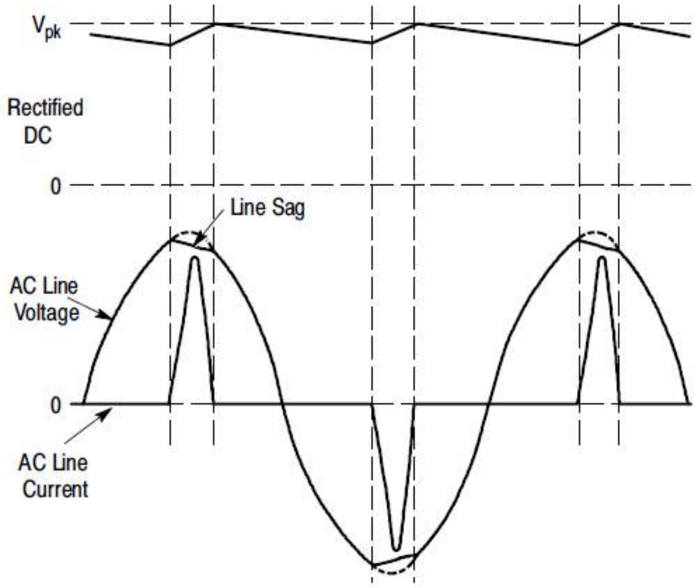

Figure 5.4: Uncorrcted power factor input waveform

The MC34262, MC33262 are high performance, critical conduction, currentmode power factor controllers specifically designed for use in offline active preconverters. These devices provide the necessary features required to significantly enhance poor power factor loads by keeping the ac line current sinusoidal and in phase with the line voltage.

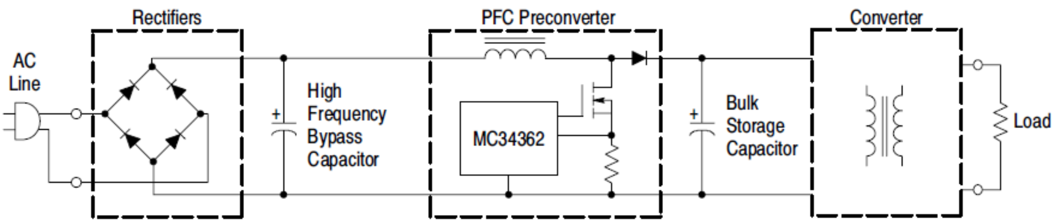

Figure 5.5: Active Power Factor Correction Preconverter

5.2 Operating Description

• Error Amplifier: An error amplifier with acess to the inverting input and output is provided. The amplifier is transconductance type, meaning that has high output impedance with controlled voltage to current gain. The noninverting input is internally biased at $2.5V \pm 2.0\%$ and is not pinned out. The output voltage of the power factor converter is typically divided down and monitored by the inverting input. The maximum input bias current is 0.5 mA, which can cause an output voltage error that is equal to the product of the input bias current and the value of the upper divider resistor R2. The Error Amp output is internally connected to the Multiplier and is pinned out (Pin 2) for external loop compensation.Typically, the bandwidth is set below 20 Hz, so that the amplifiers output voltage is relatively constant over a given ac line cycle. In effect, the error amp monitors the average output voltage of the converter over several line cycles. The Error Amp output stage was designed to have a relatively constant transconductance over temperature. This allows the designer to define the compensated bandwidth over the intended operating temperature range.

A key feature to using a transconductance type amplifier, is that the input is allowed to move independently with respect to the output, since the compensation capacitor is connected to ground. This allows dual usage of of the Voltage Feedback Input pin by the Error Amplifier and by the Overvoltage Comparator.

• Overvoltage Comparator: An Overvoltage Comparator is incorporated to eliminate the possibility of runaway output voltage. This condition can occur during initial startup, sudden load removal, or during output arcing and is the result of the low bandwidth that must be used in the Error Amplifier control loop. The Overvoltage Comparator monitors the peak output voltage of the converter, and when exceeded, immediately terminates MOSFET switching. The comparator threshold is internally set to 1.08 V_{ref}. In order to prevent false tripping during normal operation, the value of the output filter capacitor C_3 must be large enough to keep the peaktopeak ripple less than 16% of the average dc output. The Overvoltage Comparator input to

Drive Output turnoff propagation delay is typically 400 ns. A comparison of startup overshoot without and with the Overvoltage Comparator circuit is shown in Figure 23.

• Mutiplier: A single quadrant, two input multiplier is the critical element that enables this device to control power factor.The ac full wave rectified haversines are monitored at Pin 3 with respect to ground while the Error Amp output at Pin 2 is monitored with respect to the Voltage Feedback Input threshold. The Multiplier is designed to have an extremely linear transfer curve over a wide dynamic range, 0 V to 3.2 V for Pin 3, and 2.0 V to 3.75 V for Pin 2. The Multiplier output controls the Current Sense Comparator threshold as the ac voltage traverses sinusoidally from zero to peak line, Fig. 4.11. This has the effect of forcing the MOSFET ontime to track the input line voltage, resulting in a fixed Drive Output ontime, thus making the preconverter load appear to be resistive to the ac line. An approximation of the Current Sense Comparator threshold can be calculated from the following equation.

$$V_{cs}, Pin4Threshold = 0.65(V_{Pin2} - V_{Pin3})V_{Pin3}$$

A significant reduction in line current distortion can be attained by forcing the preconverter to switch as the ac line voltage crosses through zero. The forced switching is achieved by adding a controlled amount of offset to the Multiplier and Current Sense Comparator circuits. The equation shown below accounts for the builtin offsets and is accurate to within ten percent. Let $V_{th(M)} = 1.991V$.

$$V_{cs}, Pin4Threshold = 0.544(V_{Pin2} - V_{th(M)})V_{Pin3} + 0.0417(V_{Pin2} - Vth(M)$$

• Zero Current Detector: The MC34262 operates as a critical conduction current mode controller, whereby output switch conduction is initiated by the Zero Current Detector and terminated when the peak inductor current reaches the threshold level established by the Multiplier output. The Zero Current Detector initiates the next ontime by setting the RS Latch at the instant the inductor current reaches zero. This critical conduction mode of operation has two significant benefits. First, since the MOSFET cannot turnon until the inductor current reaches zero, the output rectifier reverse recovery time becomes less critical, allowing the use of an inexpensive rectifier. Second, since there are no deadtime gaps between cycles, the ac line current is continuous, thus limiting the peak switch to twice the average input current.

The Zero Current Detector indirectly senses the inductor current by monitoring when the auxiliary winding voltage falls below 1.4 V. To prevent false tripping, 200 mV of hysteresis is provided. The Zero Current Detector input is internally protected by two clamps. The upper 6.7 V clamp prevents input overvoltage breakdown while the lower 0.7 V clamp prevents substrate injection. Current limit protection of the lower clamp transistor is provided in the event that the input pin is accidentally shorted to ground. The Zero Current Detector input to Drive Output turnon propagation delay is typically 320 ns.

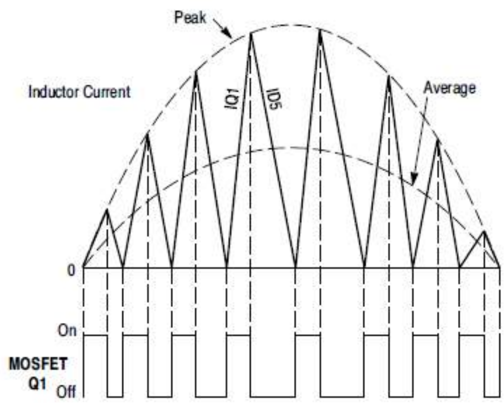

Figure 5.6: Inductor current and MOSFET gate voltage waveform

• Current Sense Comparator and RS Latch: The Current Sense Comparator RS Latch configuration used ensures that only a single pulse appears at the Drive Output during a given cycle. The inductor current is converted to a voltage by inserting a groundreferenced sense resistorR_7 in series with the source of output switch Q_1. This voltage is monitored by the Current Sense Input and compared to a level derived from the Multiplier output. The peak inductor current under normal operating conditions is controlled by the threshold voltage of Pin 4 where:

$$I_{L(pk)} = \frac{pin4Threshold}{R_7}$$

Abnormal operating conditions occur during preconverter startup at extremely high line or if output voltage sensing is lost. Under these conditions, the Multiplier output and Current Sense threshold will be internally clamped to 1.5 V. Therefore, the maximum peak switch current is limited to:

$$I_{pk(max)} = \frac{1.5V}{R_7}$$

An internal RC filter has been included to attenuate any high frequency noise that may be present on the current waveform. This filter helps reduce the ac line current distortion especially near the zero crossings. With the component values shown in Figure 20, the Current Sense Comparator threshold, at the peak of the haversine varies from 1.1 V at 90 Vac to 100 mV at 268 Vac. The Current Sense Input to Drive Output turnoff propagation delay is typically less than 200 ns.

• Timer: A watchdog timer function was added to the IC to eliminate the need for an external oscillator when used in standalone applications. The Timer provides a means to automatically start or restart the preconverter if the Drive Output has been off for more than 620 ms after the inductor current reaches zero.

• Drive Output: The MC34262/MC33262 contain a single totempole output stage specifically designed for direct drive of power MOSFETs. The Drive Output is capable of up to $\pm 500mA$ peak current with a typical rise and fall time of 50 ns with a 1.0 nF load. Additional internal circuitry has been added to keep the Drive Output in a sinking mode whenever the Undervoltage Lockout is active. This characteristic eliminates the need for an external gate pulldown resistor. The totempole output has been optimized to minimize crossconduction current during high speed operation. The addition of two 10 W resistors, one in series with the source output transistor and one in series with the sink output transistor, helps to reduce the crossconduction current and radiated noise by limiting the output rise and fall time. A 16 V clamp has been incorporated into the output stage to limit the high state V_{OH}. This prevents rupture of the MOSFET gate when V_{CC} exceeds 20 V.

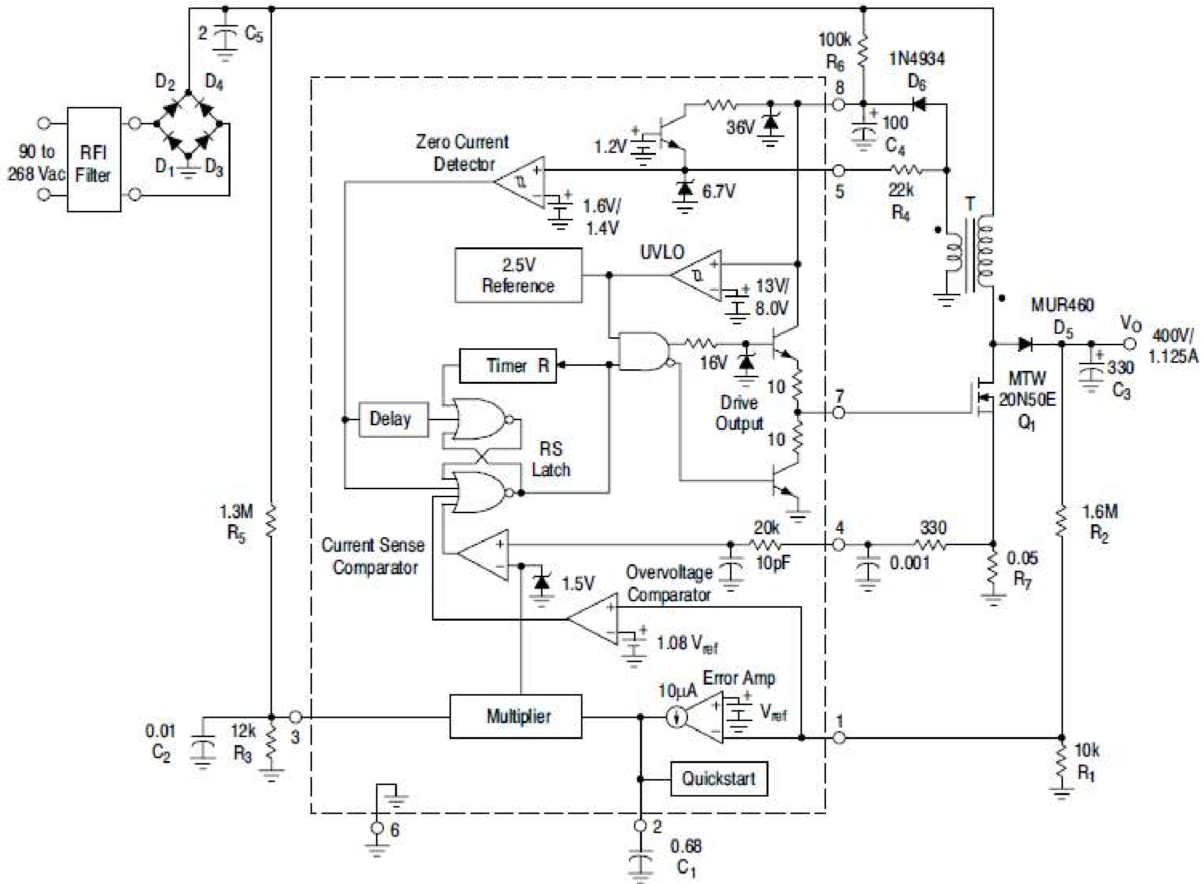

Figure 5.7: 475 W Power Factor Controller

Chapter 6

Design equations of Autotransformer, Active Interphase Transformer, PWM Inverter & Boost PFC Coverter

6.1 Autotransformer Voltage & Current Relationship

$$V_{a1,p} = V_{a,p}\sqrt{1+k_1^2}$$

$$V_{a1,p} = 1.035V_{a,p}$$

$$V_{a1,p} = 1.035\sqrt{\frac{2}{3}}V_{LL}$$

where V_{LL} is the line-to-line voltage.

- the rms value of the small (secondary) winding currents is,

$$I_a^{'} = \sqrt{\frac{2}{3}}\frac{1}{2}I_0$$

- the rms value of the large (primary) winding current is,

$$I_1 = \frac{k_1}{\sqrt{3}}\sqrt{\frac{1}{3}\frac{1}{2}}I_0$$

- the rms value of the small(secondary) winding voltage is,

$$V'_{aa} = k_1\frac{V_m}{\sqrt{2}}$$

- the rms value of the large (primary) winding voltage is,

$$V_{ab} = \sqrt{3}\frac{V_m}{\sqrt{2}}$$

- kVA rating of Autotransformer will be 22% of the total dc output power.
- to obtain required phase shift of $\phi/2$ turns ratio n is given by,

$$n = \frac{\sqrt{3}}{tan(\phi/2)}$$

- For 12-pulse converter turns ratio n is,

$$n = 6.47$$

6.2 kVA rating of Active Interphase Transformer

- the rms voltage of V_m is,

$$V_m = 0.1322V_0$$

- voltage across auxiliary winding in the Interphase Transformer is givenby,

$$V_x = (N_x/N_m)V_m$$

- The inductance of L_1 for the Interphase Reactor becomes,

$$L_1 = \frac{0.1949V'_m}{wK_1I_0}$$

where K_1 is the desired percentage ripple of load currrent I_0.

Triangular current I_xrms is given by,

$$I_xrms = 0.5798I_0\frac{V_m}{V_x}$$

- The VA rating of active interphase transformer is,

$$VA_{IR} = \frac{V_mI_o+V_xI_x}{2}$$

6.3 kVA rating of PWM inverter & boost PFC circuit

- the VA rating of PWM inverter is given by,

$$VA_{inv} = V_x I_x$$
$$VA_{inv} = 0.11P_0$$

  - The kVA rating of PWM inverter unit is percentage of the output power.
  - the voltampere rating of the boost Converter that produces I_x is as follows:

$$VA_{boost} = V_x rms I_x rms = 0.05P_0$$

System kVA	50 kVA
Input Voltage V_s	415 V
Autoransformer kVA rating	10 kVA
Autoransformer turn ratio n	6.47
IPT kva rating	4.7 kVA
Inductance of Active IPT L_1	25 mH
PWM Inverter kVA rating	5.5 kVA
Boost Converter	2.25 kVA
Output Power	45 kW
Output Voltage	580 V

Table I: Specification of the 50kVA, 415V 12-pulse converter system with Active Interphase transformer

Chapter 7

Simulation & Analysis of 50 kVA, 415 V 12-pulse Rectifier System

7.1 Simulation results of 12-pulse rectifier system when phase shift by means of autotransformer without IPT

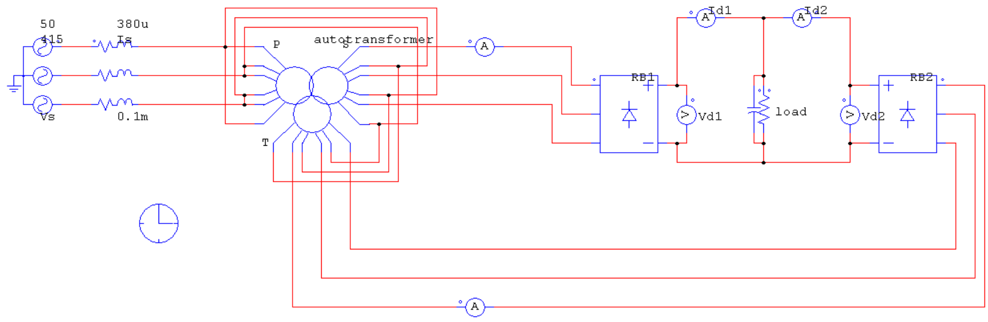

Figure 7.1: simulation circuit of 12-pulse rectifier without IPT

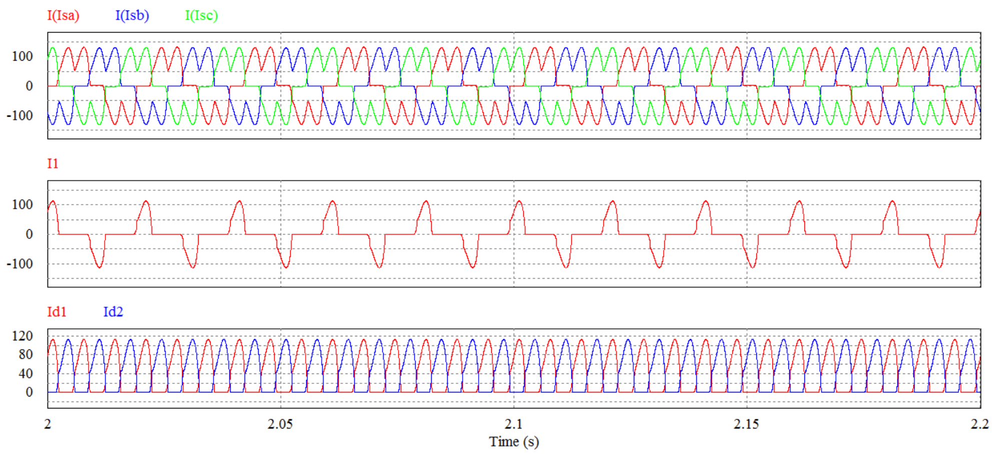

Figure 7.2: (a) supply current (Is) (b) rectifier side input current (c) output current (Id1& Id2)

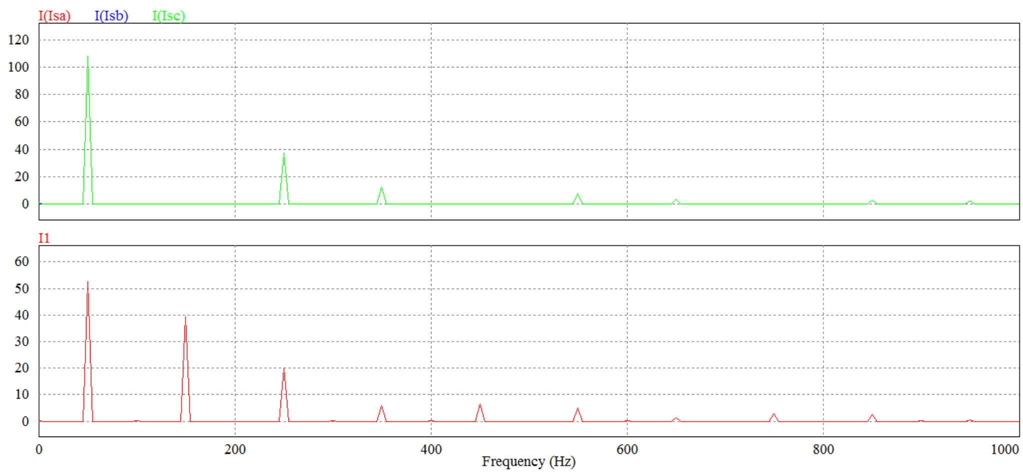

Figure 7.3: (a) FFT of supply current (Is) (b) FFT of rectifier side input current

7.2 Simulation results of 12-pulse rectifier system when phase shift by means of autotransformer with IPT

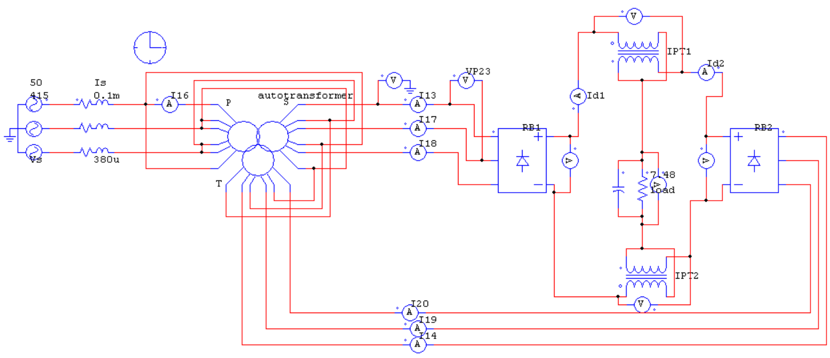

Figure 7.4: Simulation circuit of 12-pulse rectifier system with IPT

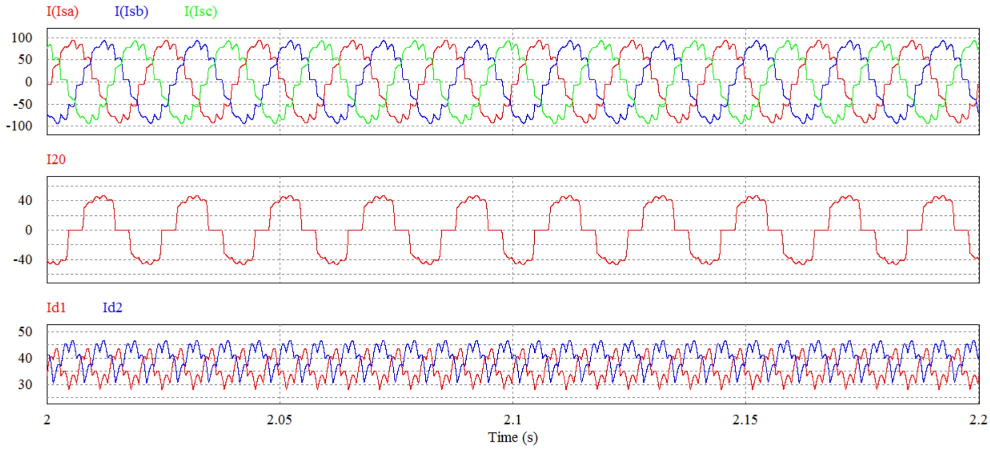

Figure 7.5: (a) supply current (Is) (b) rectifier side input current (c) output current (Id1& Id2)

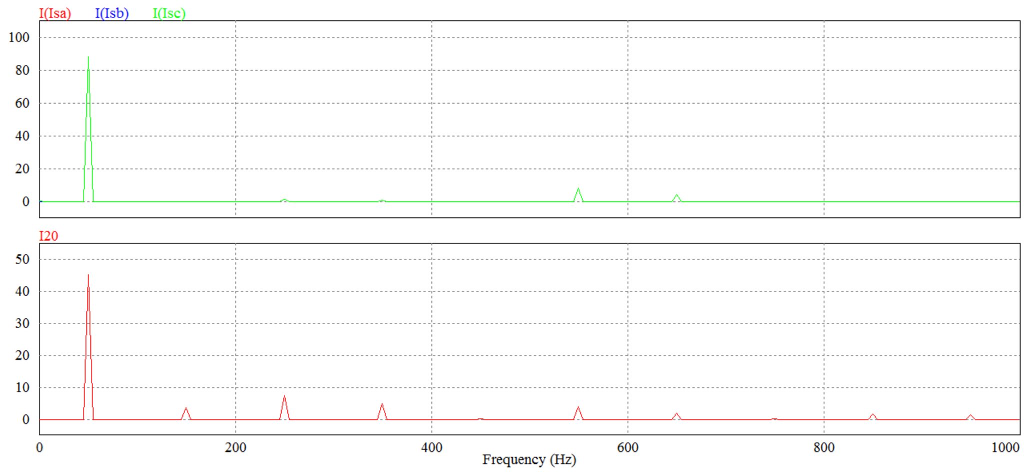

Figure 7.6: (a) FFT of supply current (Is) (b) FFT of rectifier side input current

7.3 Simulation circuit of 12-pulse rectifier system with Active Interphase Transformer

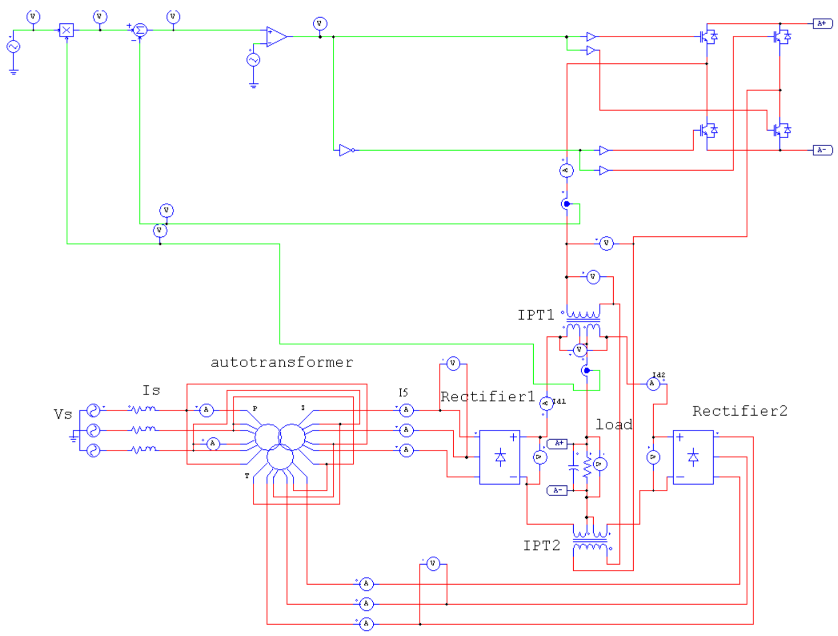

Figure 7.7: simulation circuit of 12-pulse rectifie system with Active IPT

7.3.1 Simulation results of 12-pulse rectifier system with Active IPT at 100% load

• supply current & Rectifier side input current when R_{load}= 7.48 Ω

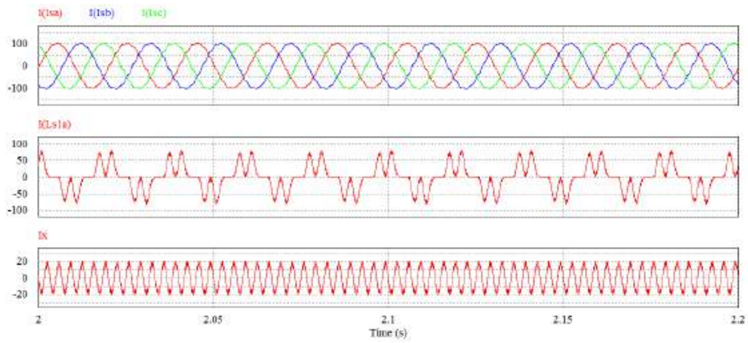

Figure 7.8: (a) supply current (b) rectifier side input current (c) Injected current (Ix)

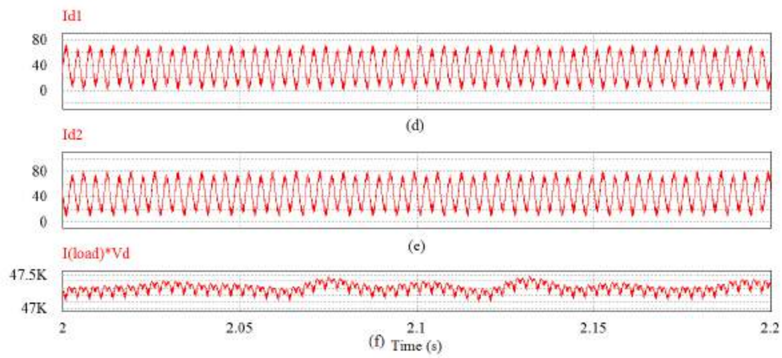

Figure 7.9: (d) Output current, fed from rectifier-1 (e) output current, fed from rectifier-2 (f) Output power

7.3.2 Simulation results of 12-pulse rectifier system with Active IPT at 75% load

• supply current & Rectifier side input current when R_{load}= 9.973 Ω

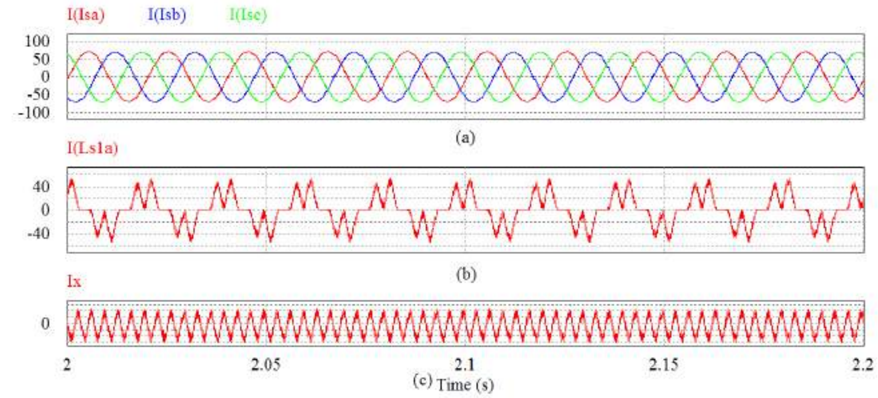

Figure 7.10: (a) supply current (b) rectifier side input current (c) Injected current (Ix)

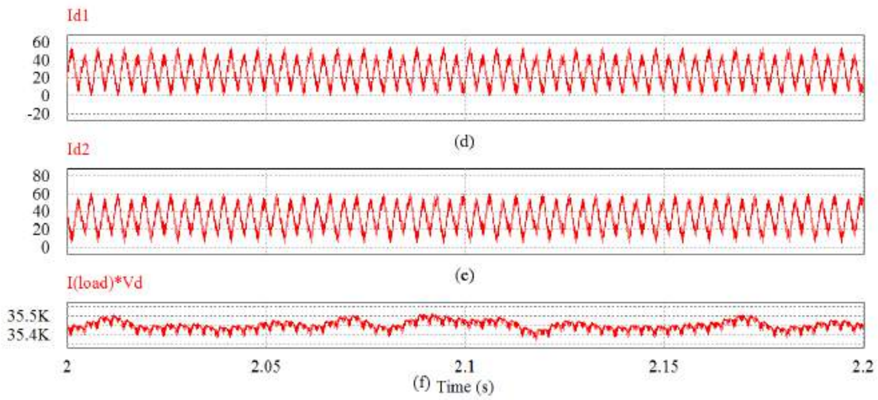

Figure 7.11: (d) Output current, fed from rectifier-1 (e) output current, fed from rectifier-2 (f) Output power

7.3.3 Simulation results of 12-pulse rectifier system with Active IPT at 50% load

- supply current & Rectifier side input current when R_{load}= 1 Ω

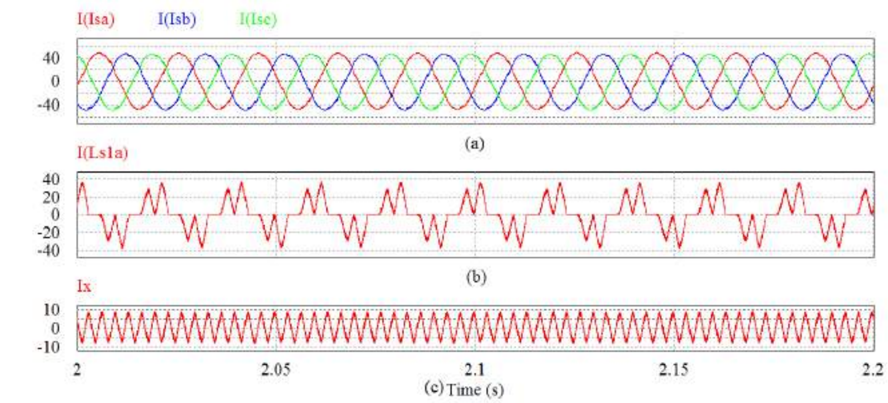

Figure 7.12: (a) supply current (b) rectifier side input current (c) Injected current (Ix)

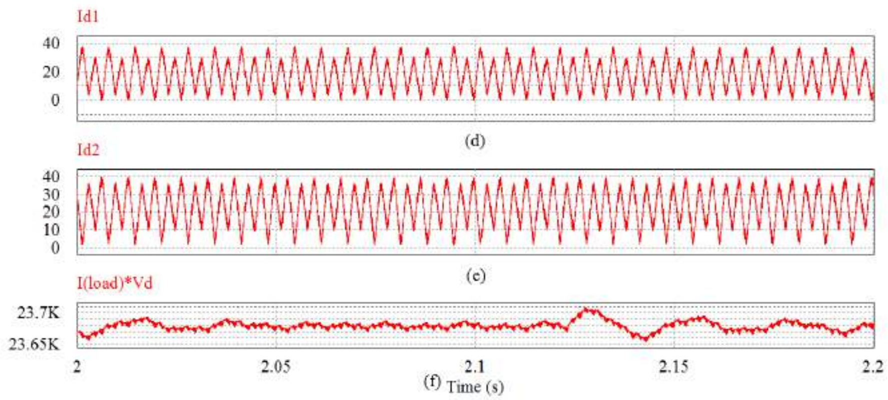

Figure 7.13: (d) Output current, fed from rectifier-1 (e) output current, fed from rectifier-2 (f) Output power

12-pulse rectifier system	% THD of supply current	% THD of rectifier side input current
Without IPT	37.4%	81%
With IPT	11.8%	34%

Table I: % THD of supply current & rectifier side input current of 12-pulse rectifier system when phase shift by mean of autotransformer

12-pulse rectifier system with Active IPT at varying load	% THD of supply current
At 100% load	2.8%
At 75% load	2.8%
At 50% load	3.7%

Table II: % THD of supply current for varying load condition when current I_x injected into Avtive IPT

7.4 Simulation circuit of 12-pulse rectifier system with boost Converter & Active IPT

- % THD of supply current is 4.9%.

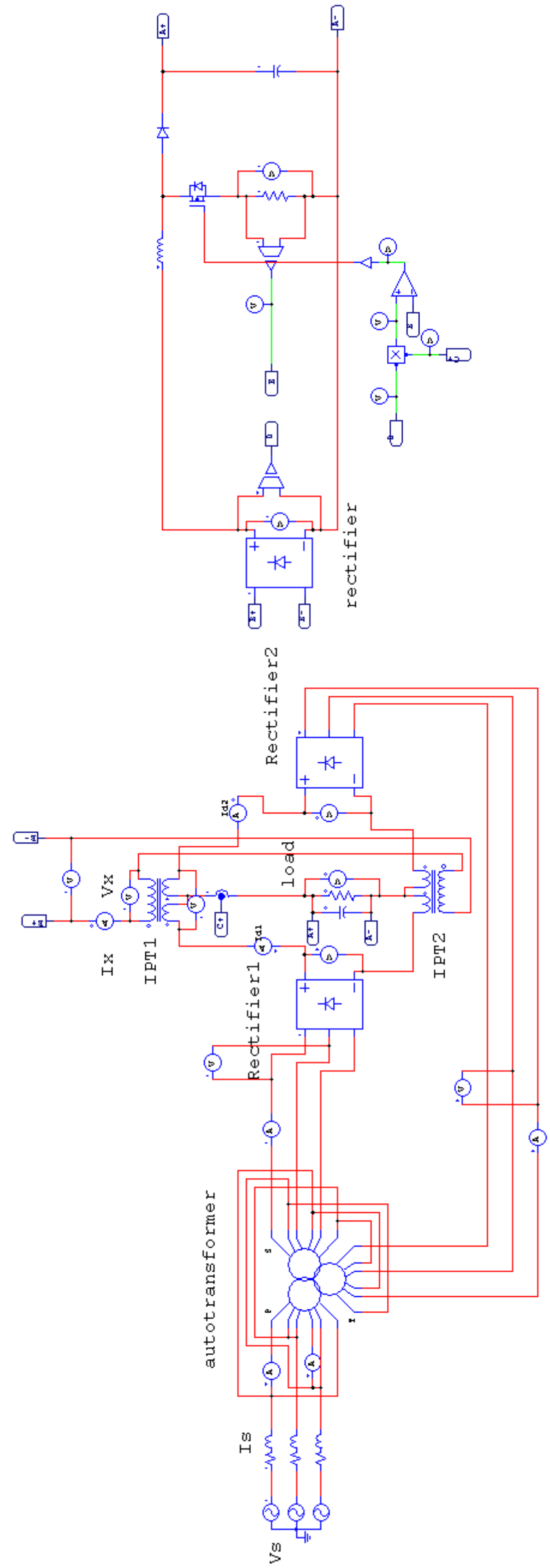

Figure 7.14: Simulation circuit of 12-pulse rectifier system with boost converter & Active IPT

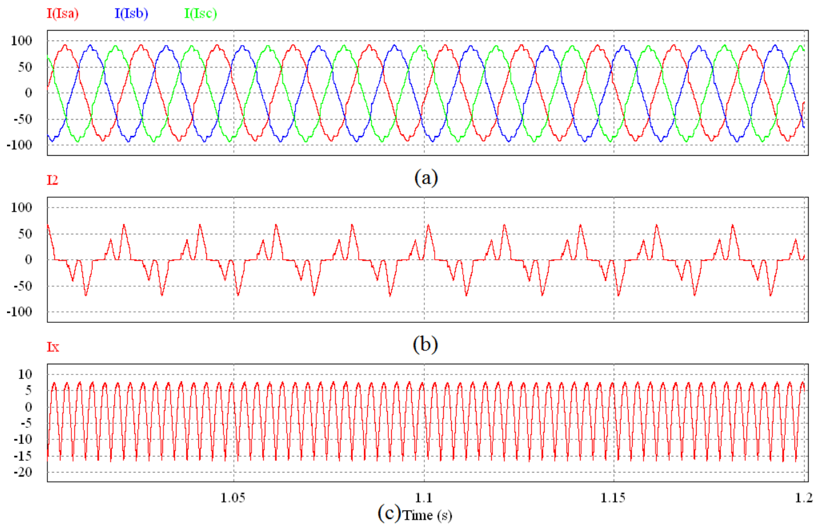

Figure 7.15: (a) supply current (b) rectifier side input current (c) Injected current (Ix)

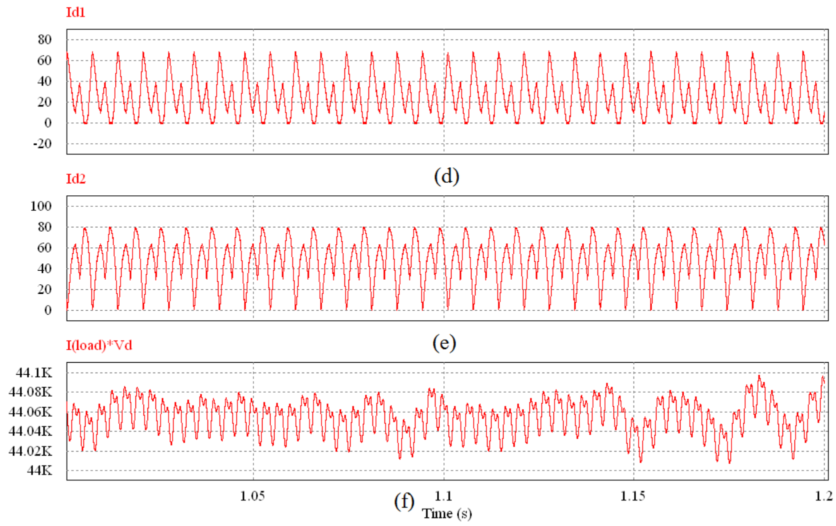

Figure 7.16: (d) Output current, fed from rectifier-1 (e) output current, fed from rectifier-2 (f) Output power

Chapter 8

Hardware Approach

8.1 Delta Connected Autotransformer

- 10 kVA, Primary : 415 V & Secondary: 64 V delta connected autotransformer.

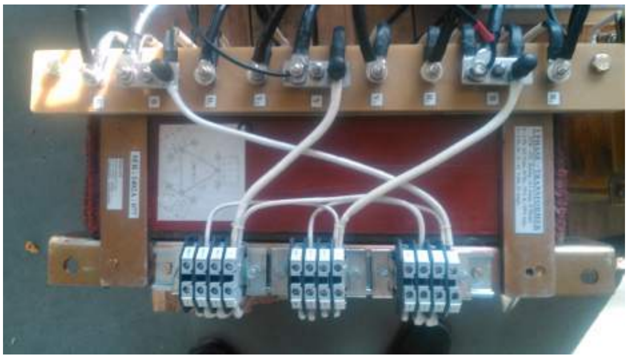

Figure 8.1: 10 kVA Delta Connected Autotransformer

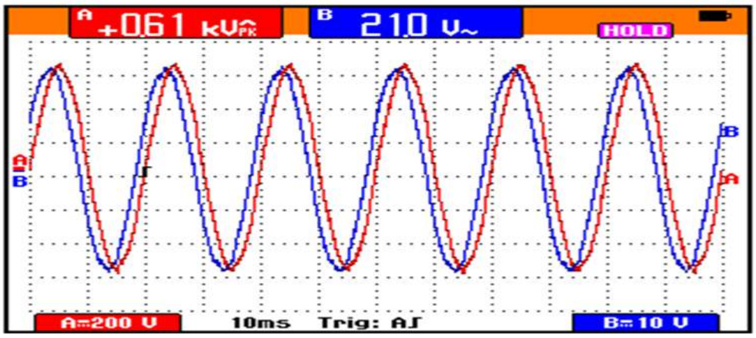

Figure 8.2: 30^0 phase shifted votage waveforms to recctifier Bridge I & II

8.2 Active Interphase Transformer

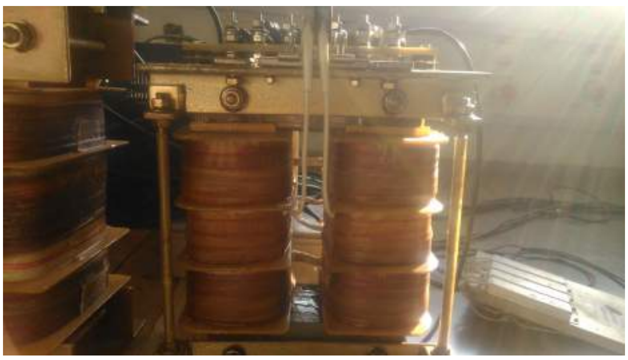

Figure 8.3: 9 kVA Avtive Interphase Transformer

8.3 Hardware setup for 50 kVA, 415 V 12-pulse rectifier system with Active IPT & Autotransformer

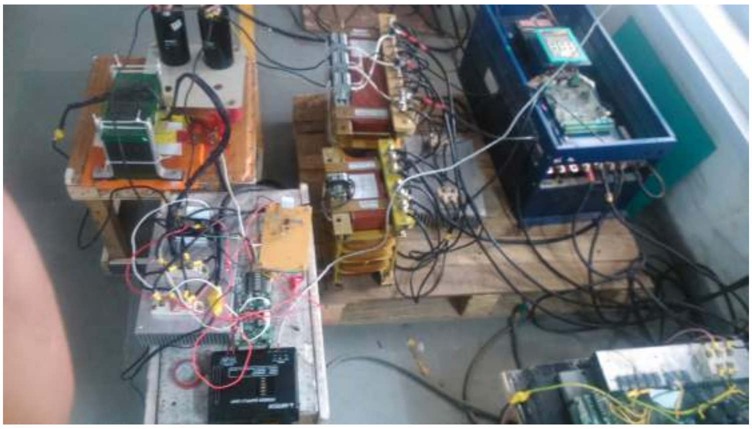

Figure 8.4: Hardware setup for 50 kVA, 415 V 12-pulse rectifier system with Active IPT & Autotransformer

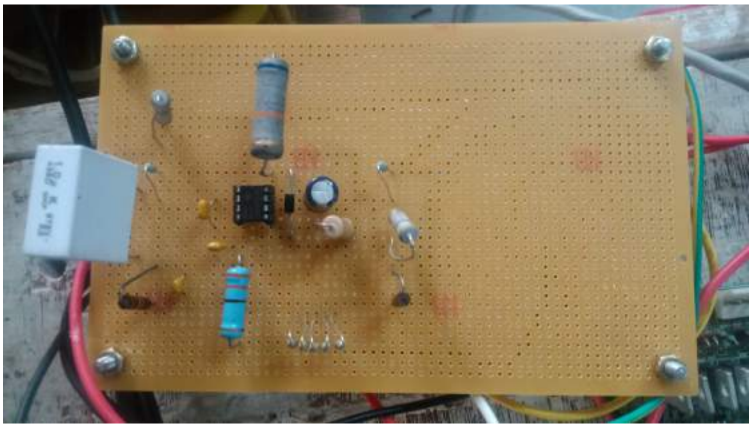

Figure 8.5: MC34262-Power Factor Controller IC

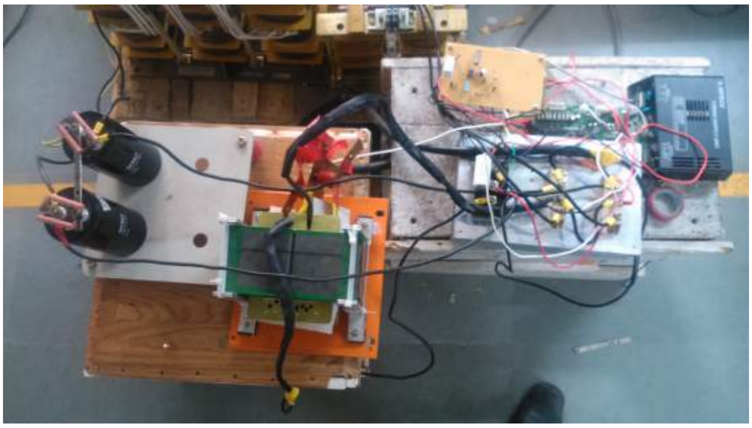

Figure 8.6: Boost Converter

8.4 Hardware results for 50 kVA, 415 V 12-pulse rectifier system without Active IPT

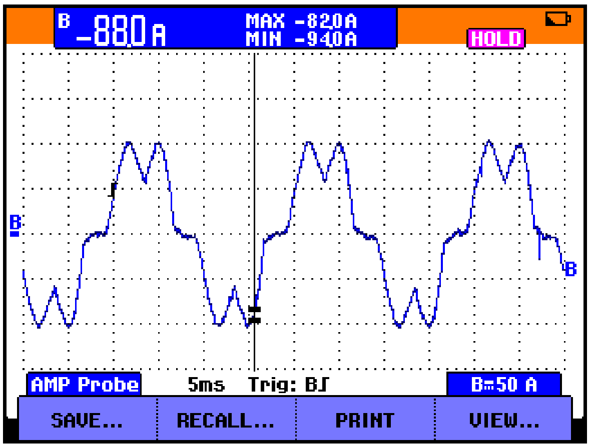

Figure 8.7: Supply current waveform

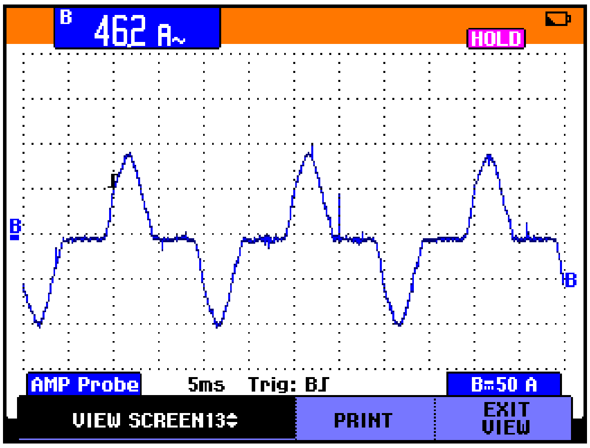

Figure 8.8: Rectifier Side Input current waveform

V_s (V)	V_{dc} (V)	I_s (A)	I_d (A)	I_{d1} (A)	I_{d2} (A)	% THD of I_s	Power Factor
406	595	72	76.5	34.9	39.1	36.5	0.9
406	595	64.8	62.4	28.9	30.3	41.2	0.88
406	595	57.6	54	27	28.8	44.8	0.85
406	595	50.4	45.6	22.4	23.3	46.9	0.84
406	595	43.2	36.8	18.2	18.5	52.6	0.82
406	595	36	26.7	13	14.1	57.4	0.79
406	595	28.8	20.3	10.6	10.4	59.6	0.76
406	595	21.6	15.2	8.3	8.1	63.7	0.75

Table I: Suppily Current & rectifier side input current THD of 415 V, 50 kVA 12-pulse rectifier system at varing load condition with Active IPT, without current injection I_x

8.5 Hardware results for 50 kVA, 415 V 12-pulse rectifier system with Active IPT, without current injection I_x

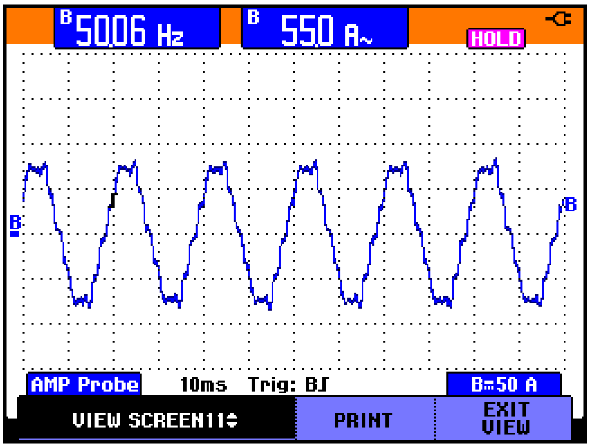

Figure 8.9: Supply current waveform I_s

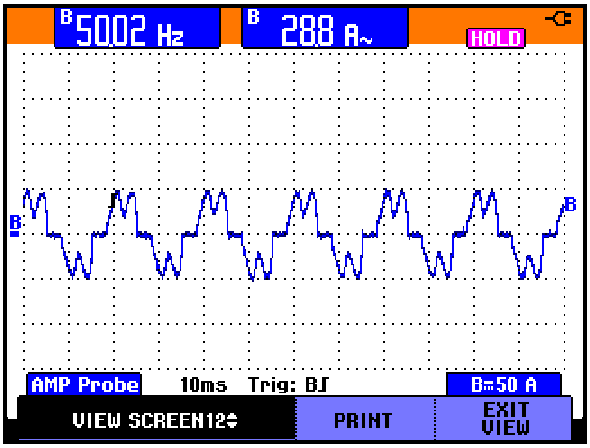

Figure 8.10: Rectifier Side Input current waveform I_{r1}

8.6 Hardware results for 50 kVA, 415 V 12-pulse rectifier system with Active IPT, with current injection I_x

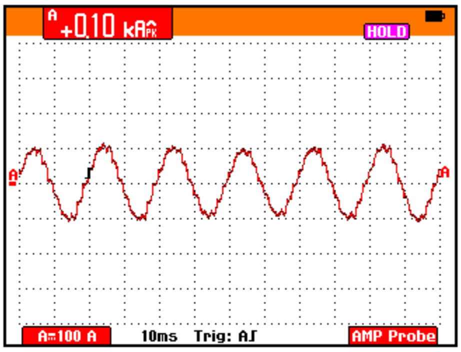

Figure 8.11: Supply current waveform I_s

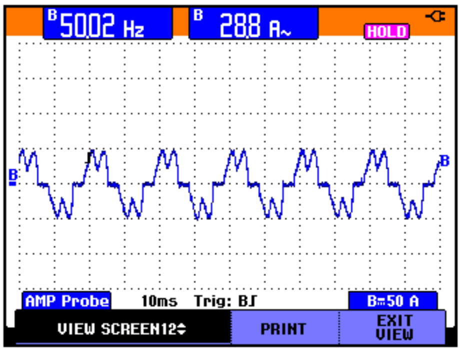

Figure 8.12: Rectifier Side Input current waveform I_{r1}

- Supply current THD with current injection I_x into auxiliary winding of active interphase transformer is 8.8%.

V_s (V)	V_{dc} (V)	I_s (A)	I_d (A)	I_{d1} (A)	I_{d2} (A)	% THD of I_s	% THD of I_{r1}	% THD of I_{r2}	Power Factor
404	550	66.7	80	41.5	39.2	11	33	34	0.98
404	550	60.3	73.5	39.1	37.9	11	35.6	33	0.97
404	550	53.6	65.3	32.9	33.3	12.3	38.4	36.5	0.97
404	550	46.9	56.6	28.7	29	13	39.3	36.5	0.97
404	550	40.2	49.7	24.5	26	14.2	41	37.8	0.97
404	550	33.5	42.3	23.2	25.2	15.2	44.7	41.3	0.97
404	550	26.68	33	16.3	18.7	19.3	50.5	45.7	0.97
404	550	20.01	24	12	13.8	23.4	55.7	51.7	0.97
404	550	13.34	15.7	6.5	10.3	28	64.4	53.8	0.97
404	550	7.2	8.7	3.3	5.7	30	65.6	54	0.97

Table II: Suppily Current & rectifier side input current THD of 415 V, 50 kVA 12-pulse rectifier system at varing load condition with Active IPT, without current injection I_x

Chapter 9

Conclusion and Future Scope

9.1 Conclusion

By incorporating the uncontrolled IPT in 12-pulse rectifier system (phase shift by autotransformer) equal current flow through both the converters, there by reducing the overheating of semiconductor devices. Also provide maximum power & minimum harmonic content in utility line current. By using uncontrolled IPT %THD can be reduced up to 11.8% lesser than that of the 12-pulse rectifier system without IPT. It will also negate the zero-sequence harmonic current coming on rectifier side input current. By incorporating active IPT in 12-pulse rectifier system, it will draw near sinusoidal current from utility (%THD $\leq$ 5%). This system is suitable for utility interface of high power ac motor drive system to meet the current IEEE-519 harmonic current limit. If PWM VSI or boost PFC circuit malfunctions, this system will revert to 12-pulse operation with 5^{th} & 7^{th} harmonics cancellation in utility line current. Both schemes will give superior performance with reduced kVA component. Simulation results have been shown for both scheme I & II for 415 V, 50 kVA 12-pulse rectifier system. Hardware results have been shown for Active Interpahse Transformer with Boost PFC Circuit for 415 V, 50 kVA 12-pulse rectifier system.

9.2 Future Scope

- A prototype model for 12-pulse rectifier system with autotransformer arrangement in which PWM VSI is employed to inject triangualr shaped current into auxiliary windig of Active Interphase Transformer.

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