© November 2025 | IJIRT | Volume 12 Issue 6 | ISSN: 2349-6002

Modeling Of Multi Dc Input - Ac, 3φ, 400hz Output Hybrid Converter for Under Water Marine Platform Controls

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Abstract—**Marine platforms rely on advanced Control systems to manage and monitor essential operations such as Power Generation & Distribution, Propulsion Control, General Ship system and Central coordination of functions. These systems typically operate at 400Hz to ensure reliable, stable, & fault-tolerant power delivery for subsea equipment incl. sensors, actuators & communication devices. A 3-Tier reliability architecture - comprising Main, Reserve & Emergency mode to ensure power supply availability in all regime's operation.**

This project analyzes the behaviour and common defects of existing Russian-made DC-AC Rotary frequency converter fitted onboard underwater platform, offering both short- and long-term solutions. The cost and availability of spares, largely imported, are significant concerns.

The converter under study (I/P: 175–320V DC, O/P: 3Ph, 230V, 400Hz, 50KW) uses a DC Compound Motor and AC Generator mounted on a common shaft. Its heavy rotary armature makes unit bulky, difficult to handle, and alignment onboard. This system produces significant noise and requires frequent maintenance due to issues such as Excitation circuit repairs and cleaning of commutator, slip-rings, and carbon brushes. Additionally, Compatibility issues with onboard AC-AC rotary frequency converters (50–400Hz, 50KW, two units) complicate repairs at sea using cannibalized parts, affecting operational reliability.

To mitigate these issues, all three onboard frequency converters (two AC-AC and one DC-AC) have undergone component homogenization through local Indigenization, reducing reliance on imports and improving part compatibility. Integration of modern Static power electronic devices enhances control over non-linear loads, while optimizing the DC-DC conversion stage prior to inversion provides a more stable, regulated DC link voltage, lessening strain on the final conversion process and boosting power quality at the distribution level. Additionally, employing permanent magnet rotor-based motor-generator sets as rotary converters further simplifies mechanical construction and logistics, making installation and maintenance more efficient for marine applications.

I. INTRODUCTION

1.1 Introduction

In marine platforms, widely used 400HZ as Control supply for Sensors, Actuators and Communication systems, where available power sources are Diesel Generator & Turbo Alternator are at 50Hz and DC source only.

The Control Systems are indispensable for any marine platform and have been designed to operate on 3-Tier reliability (Main, Reserve and Emergency) for ensuring availability of power supply in all operating regimes of marine platform. The above configuration has been designed by a separate distribution network feeding from 02 in nos. AC 415V, 3Ph, 50Hz - AC 230V, 3Ph, 400Hz, 50KW (Main & Reserve) and 01 No. 175-320V DC (power supply from Battery) - AC 230V, 3Ph, 400Hz, 50KW (Emergency) Rotary Frequency Converters.

1.2 Literature Survey - Case Study on Existing DC-AC Rotary Converter (Russian made) installed in Marine Platforms:

DC (175-320V) to AC (230V, 3Ph, 400Hz, 50KW) Rotary Frequency Converter consists of DC compound Motor and AC Generator installed on common shaft. It is a heavy rotary machine and having difficulty for shipping-in, alignment and its installation. Further, it is also creating heavy rotational noise and frequent maintenance issues viz, repair on excitation circuit, cleaning of Commutator, Slip-rings, Carbon Brushes, bearings, etc.

1.3 Problem formulation - Challenges faced in Current Architecture (R):
As part of Setting to Work and Trials, a no. of defects have been observed on DC-AC rotary converter fitted on-board and defects have been analyzed and providing solutions for short and long term with advent power electronic Static devices for the control of non-linear loads. Additionally, Compatibility issues with onboard AC-AC rotary frequency converters (50–400Hz, 50KW, two units) complicate repairs at sea using cannibalized parts, affecting operational reliability. The cost and availability of spares, largely imported, are significant concerns.

1.4 Objective of Thesis - Method of Homogenization of Machine components through Indigenization:
Homogenization of its Rotary Machine components through Indigenization has been worked out for all 03 in nos. frequency converters (02 in nos. AC-AC & 01 in no. DC-AC) with advent power electronic Static devices for control the non-linear loads. And employing Permanent magnet Rotor based Motor-Generator set as Rotary Converter further simplifies mechanical construction and logistics, making installation & maintenance more efficient for marine applications.
The refore, development of Hybrid converter (Static controlled Permanent magnet Frequency Rotary converter) is being proposed.

1.5 Organization of Thesis: Critical Design of 50KW Permanent Magnetic Frequency Converter:
Integration of modern Static power electronic devices enhances control over non-linear loads, while optimizing the DC-DC conversion stage prior to inversion provides a more stable, regulated DC link voltage, lessening strain on the final conversion process and boosting power quality at the distribution level. Additionally, employing permanent magnet rotor-based motor-generator sets as rotary converters further simplifies mechanical construction and logistics, making installation and maintenance more efficient for marine applications 50% of frequency up-gradation by advent power electronic Static devices using PWM controlled IGBT based Inverter. Rotary converter standardized for 200HZ to 400HZ for all 03 in nos. frequency converters (02 in nos. AC-AC & 01 in no. DC-AC). Permanent Magnet AC Synchronous Moto# Generator gives Harmonic free, Pure sinusoidal wave form output. And Simulation results of DC-AC Hybrid Converter and Onboard trials are been indicated further.

II. METHOD OF HOMOGENIZATION OF M/C COMPONENTS THROUGH INDIGENIZATION

2.1 System Requirement:
The Control Systems are indispensable for any marine platform and have been designed to operate on 3-Tier reliability (Main, Reserve and Emergency) for ensuring availability of power supply in all operating regimes of marine platform. The above configuration has been designed by a separate distribution network feeding from 02 in nos. AC 415V, 3Ph, 50Hz - AC 230V, 3Ph, 400Hz, 50KW (Main & Reserve) and 01 No. 175-320V DC (power supply from Battery) - AC 230V, 3Ph, 400Hz, 50KW (Emergency) Rotary Frequency Converters.

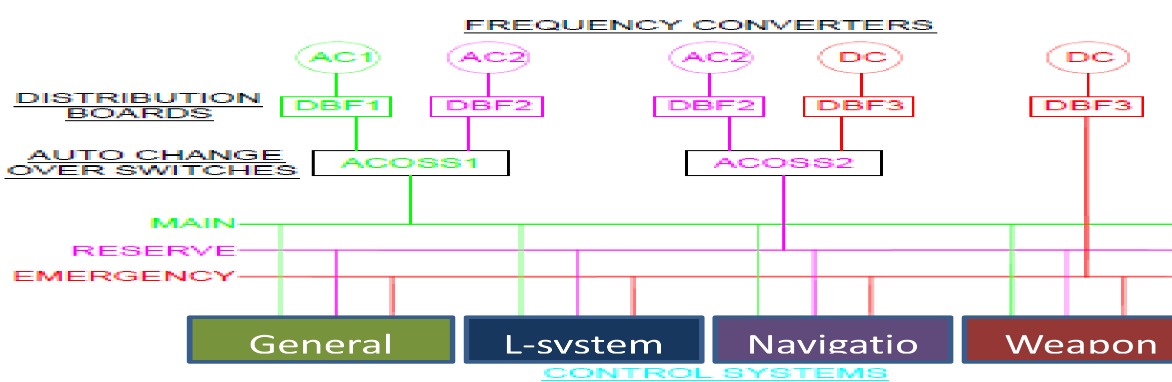


Fig.4.1 Configuration of 400HZ power supply network

- Consumers Load- 22 KW.
- Rotary Converters each capacity - 50KW
- 01 Converter always supply the load and the other
  02 converters in Hot-standby

2.2 Reason for Indigenization development of DC-AC Rotary Converter: Challenge:

Parameter	Challenge
Compatibility	Unique type Rotary M/c for AC-AC & DC-AC. Can't be Interchangeable
Dimensions	Input of converter motor designed for 50Hz, not Compact due to Commutator Assembly
Cost effective	Costlier view import (More excise duty & Taxes)
Low efficiency	Fully Rotary part (losses are more)
Operation	Too noisy view Brushes/slip rings and other hardware
Availability of Spares	More lead time to arrange spare view imported from Russia.
Weight impact	Bulk and requires huge shock mount and other structural base arrangements
Maintenance	Periodic replacement of brushes (view wear and tear)

Opportunity Area for Improvement:

Parameter	Opportunity
Compatibility	To design /develop homogenous machine for multiple purposes
Dimensions	Hybrid type M/c for conversion (Static + Rotary)
Efficiency/Operation	Usage of High-end electronics (IGBTs.)
Availability of Spares	Indigenized
Cost effective	
Weight impact	Technology/Hardware selection
Heat Output	Reduced heat output
Maintenance	Minimal (Permanent Magnet Combined Rotor)

2.3 Reliability Improvement through Homogenization of M/C components:

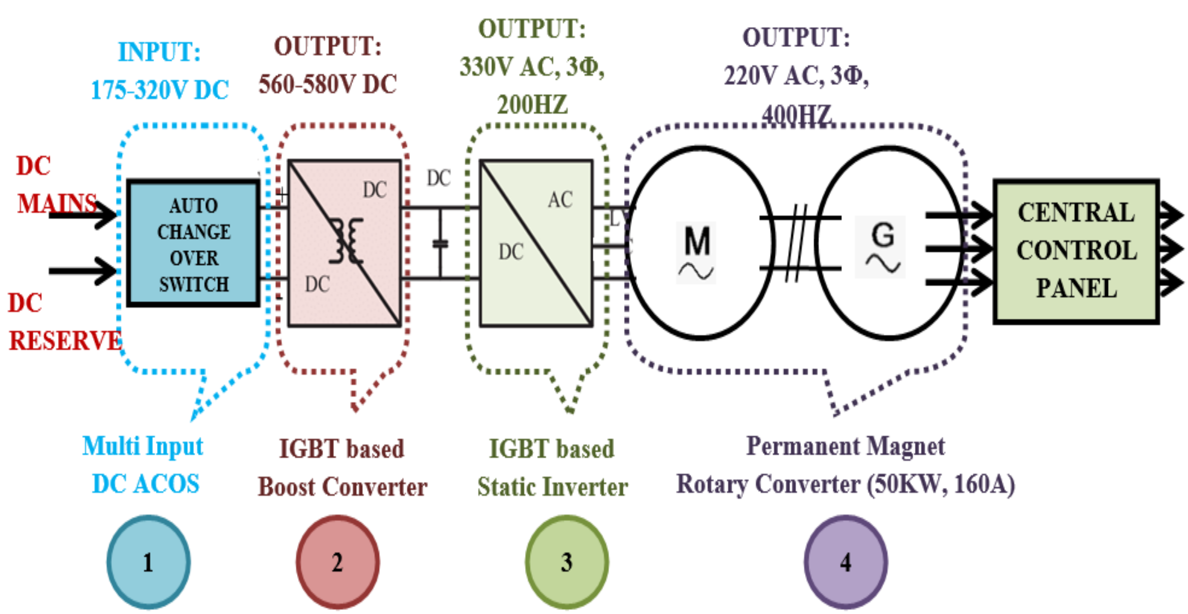


Fig.4.2 Conceptual block Diagram of DC-AC 400HZ Hybrid converter

Step-1: IGBT based controlled ACOS (Auto Change Over Switch) switched between Mains to Reserve mode within 40mSec based on their voltage levels.
Step-2: 3-Ph Interleaved Boost Chopper which boost variable DC input voltage of 175-320V DC to 700V DC. Optimize the DC-DC conversion stage before the inverter to provide a more stable, regulated DC link voltage, reducing stress on the final conversion stage.
Step-3: 3-Ph IGBT Inverter is used to convert the const. DC link voltage generated by Boost Chopper to a constant 3-Ph AC voltage, fed to Stator winding of Permanent Magnet Rotor Motor, which coupled to Generator. Inverter unit compensate the distribution side reactive and real power and improve the power quality.
Step-4: Permanent Magnet Rotary Converter (50KW, 160A) Stator is designed for Motor supply of 330V AC, 200HZ and Generator supply of 220V AC, 400HZ. Permanent Magnet AC synchronous Motor # Generator gives Harmonic free, Pure sinusoidal wave form output.Here 50% frequency up-gradation doing by Static converter using PWM controlled IGBT based Inverter.
Rotary converter standardized for 200HZ to 400HZ, hence size reduced and on-board shipping-in challenge addressed.
Maintaining const. DC bus b/w Step-2 and 3 before the inverter with advent power electronic Static devices for the control of non-linear loads, which provide a more stable, regulated DC link voltage, reducing stress on the final conversion stage.
Refer to Step-3 & 4 i.e., Inverter unit & Rotary Converter units are same for both DC-AC and AC-AC converters.

Because of this Homogenization of components through indigenization, all 03 in nos. frequency converters (02 in nos. AC-AC & 01 in no. DC-AC) On-board repair reliability has been improved by cannibalizing the components during sailing also.

III. CRITICAL DESIGN OF 50KW HYBRID CONVERTER (STATIC CONTOLLED PERMENENT MAGNET ROTARY UNIT)

3.1 Introduction:

3.1.1 Syste Purpose Of 50kw Dc-Ac Pmrfc 50 kW Permanent Magnet Rotary Frequency Converter (PMRFC) system is used to convert the frequency of input power supply to the desired 400Hz output frequency with 50kW Power. The system is designed for 175-320V variable DC input power and deliver 230V, 3-Phase, 400Hz output with 50kW of power. Local Control Panel (LCP) is employed to convert incoming variable voltage 175-320V DC to the 330V AC, 200Hz input to the PM machine which is required for generating 230V, 3-Phase, 400Hz output with 50kW of power.

3.1.2 System Scope:
PMFC System shall control and supply 230V, 3 Phase, 400Hz, 50kW power with the following subsystems:
(a) 50 kW PM Machine
(b) LCP: Consist of LCP Panel and Inverter Panel
The PMFC shall have interface with the external systems such as LCS (Electrical Control System)

3.1.3 System Overview:

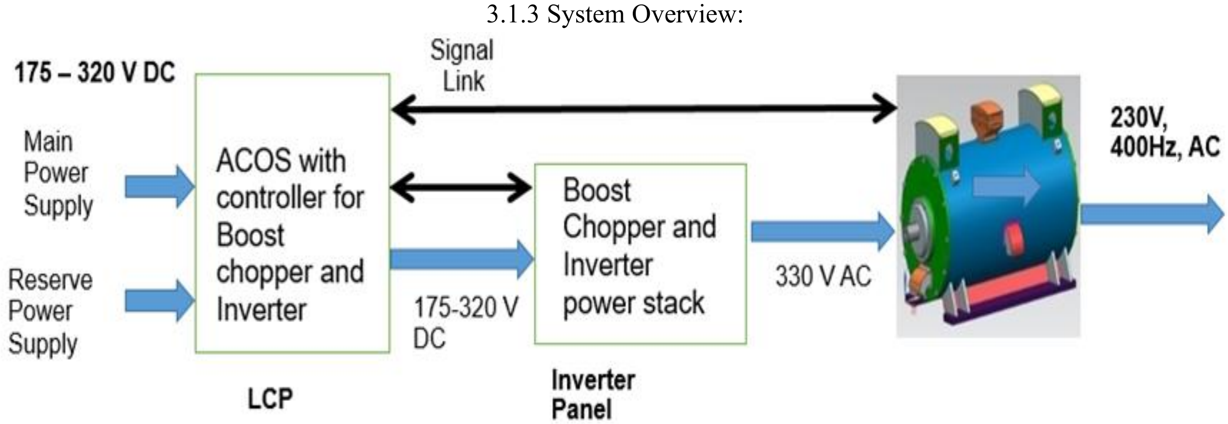


Figure 5.1: Dc Ac Pmfc Overview Diagram

Permanent Magnet technology-based Frequency Converter (PMFC) consists of a Permanent Magnet machine and a LCP (controller) to drive the machine. The power circuit mainly consists of an Automatic Change over Switch (ACOS) at its input, boost chopper for enhancing the voltage level and IGBT based 3 phase inverters for generating voltage to drive the motor of PM machine. In addition to power circuit the system includes filters at both input and output side. An EMI filter at input side is included to filter the noise entering into the system and output filter protects the motor from harmonic generated by the inverter. The control system consists of adigital signal processor-based controller with PM motor control algorithm in its heart. The system is supported by auxiliary control circuits which implement the external interface and protection functions for the system.

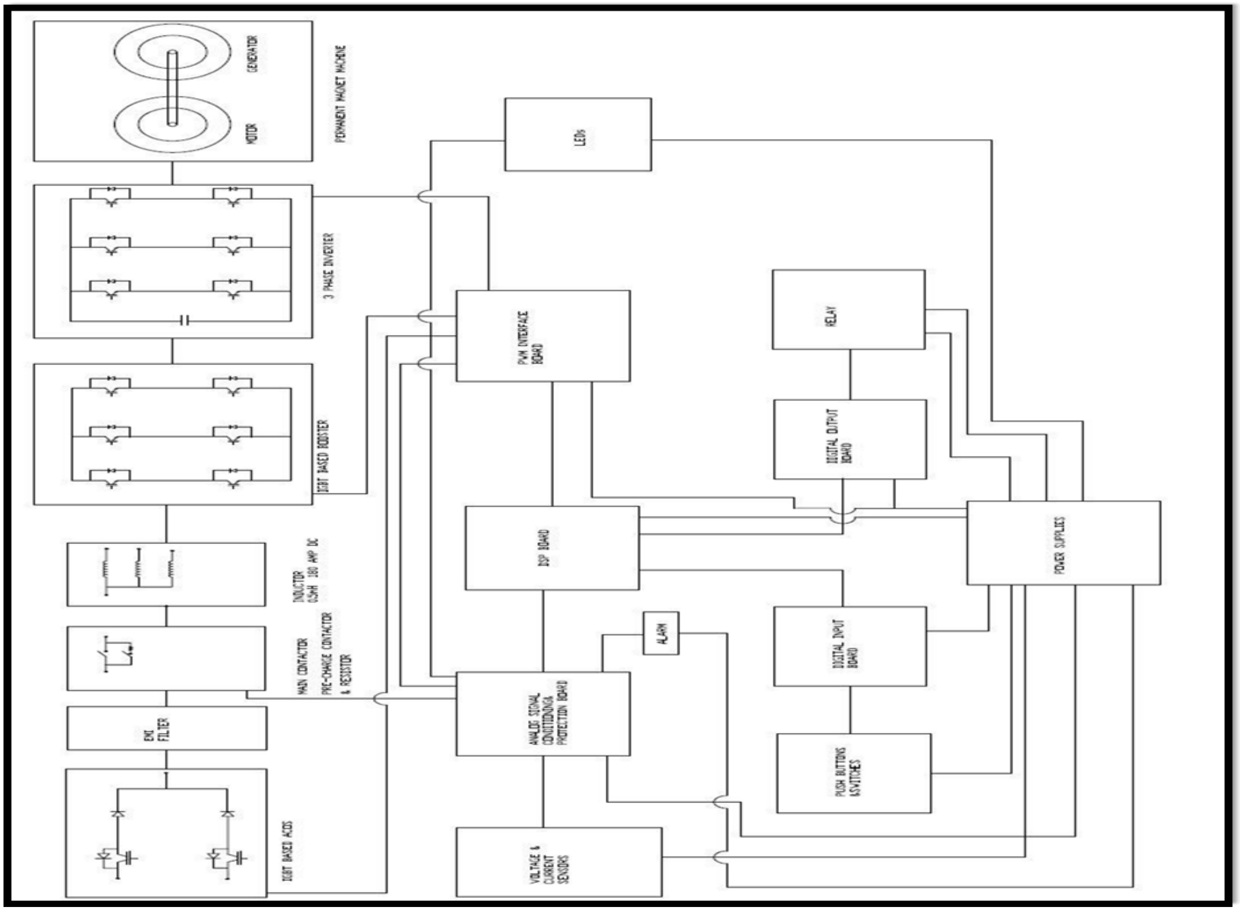


Figure 5.5: System Block Diagram Of 50kw Dc-Ac Pmfc System

3.3 Overview of Hardware Requirement Specification, Hardware Design, Drawings and Schemes:
There is a requirement of system which is used for converting DC Input Supply (175-320V DC) or AC input supply (380-415V, 3 Phase, 50Hz) to 230V,3 Phase, 400 Hz output supply with 50kW of Power using Rotary converter. Following Hardware are required to fulfill the above system requirements.
(a) LCP (Local Control Panel)
(b) PMFC (Permanent Magnet Motor-Generator set)

3.3.1 Hardware Design of Local Control Panel (LCP):
Local Control Panel (LCP) accommodates various devices which is used to drive the Permanent Magnet Motor to 3000PMFC of Permanent Magnet Motor Generator set. It switches between main and reserve power supply during power supply failure. It monitors the system parameters and trip the system in case of emergency. It ensures the healthy operation of the system. Local Control Panel is designed to be housed in two panels, LCP Panel and Inverter Panel.

Major Components present inside LCP Panel of 50kW DCAC PMFC are IGBT based ACOS, DC EMI/EMC Filter, DC Contactors, Precharge Contactor, Precharge Resistor, DCDC Power supplies, DSP+FPGA Board along with Interface Cards, Current and Voltage sensors.

Major Components present inside Inverter Panel of 50kW DC AC PMFC are Inductor, IGBT based Boost Chopper and 3 Phase Inverter, Current and Voltage sensors. Major Components present inside Inverter Panel of 50kW DC-AC/AC-AC PMFC are Inductor, IGBT based Front End Converter and 3 Phase Inverter, Current and Voltage sensors.

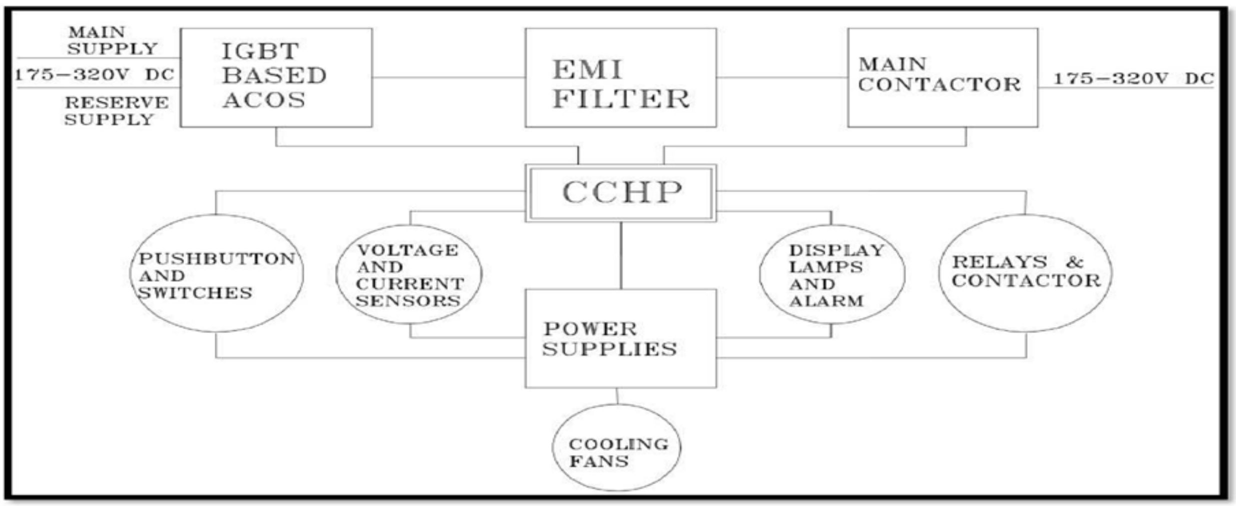


Figure 5.6 Functional Block Diagram of Lcp Unit

3.3.1.1 Automatic Change Over Switch (ACOS)

Automatic Change over Switch (ACOS) system is to switch between main and reserve power supply during power supply failure. There are two identical power supplies available at the input of the system, main power supply and reserve power supply. ACOS system switches between two power supplies based on their voltage levels and connect the next stage of the system to the available healthy power supply.

Automatic Change over Switch (ACOS) system of 50kW DC AC PMFC:

In 50kW DC AC PMFC, Contactor based ACOS system is used. Input to the ACOS system is 175-320V DC. ACOS consists of two double Pole DC contactors along with diode modules and RC snubber circuit. The circuit is shown below:

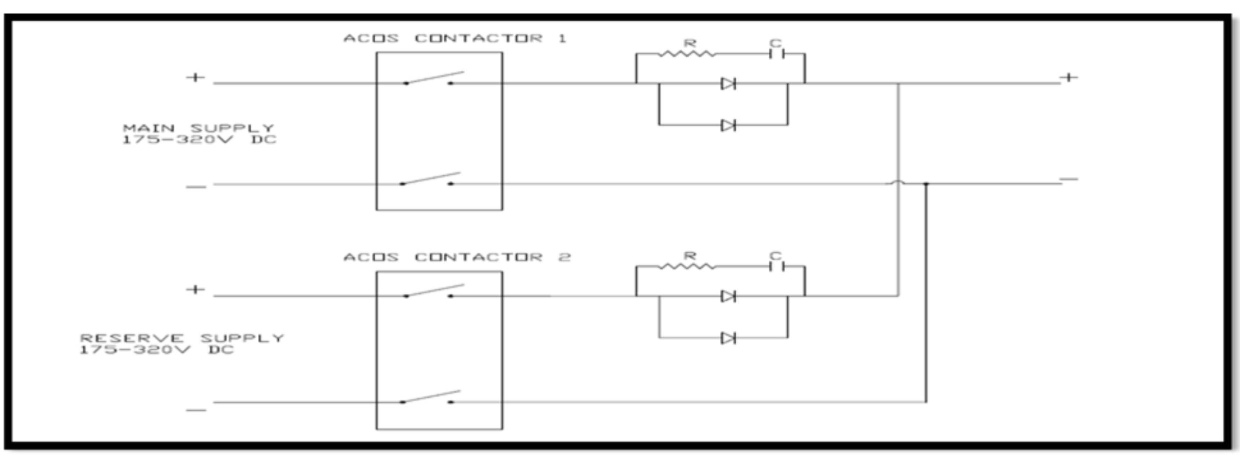


Figure 5.7 Block Diagram of Contactor Based Acos System

Two DC contactors (ACOS Contactor 1 & ACOS Contactor 2) are controlled electronically by digital signal processor (DSP) for their switch on/off operations. The voltage level at two input power sources is sensed by two voltage sensors. The outputs of sensors are fed to DSP which continuously monitors the voltages at the inputs and generates the commands signal for switch over between sources in case of power failure. The DSP operates at 150 MHz (6.67ns cycle time) which is fast enough to generate the control commands for switch over within1 milliseconds. The operation time of selected input contactors is 110 milliseconds maximum. With above the total switch over operation time is expected to be within 120 milliseconds. Contactor Rating: 2 Pole, 400Amp (550C), 320V DC,Control Voltage: 24V DC

Snubber Details:

R and C values: Value of R is 500 Ohm; 100 W. Value of C is 40 micro-Farad and voltage rating 1200 V. R and C is shown in above figure

Snubber Diode: Maximum Peak current flowing through snubber diode is 600 amps for 0.2 msec.

3.3.1.2 EMI Filter:

An EMI filter at input side is included to filter the noise entering into the system. It helps to control conducted emissions of the system and therefore significantly reduce the potential for high frequency (HF) interference radiation. The filter also protects the system from HF stray and leakage currents.

EMI Filter of 50kW DC AC PMFC

Maximum continuous operating voltage: 1200V DC,

Operating frequency: DC,

Rated currents: 600 Amp at 55°C

Figure 5.8 Block Diagram Of Dc Emi Filter

3.3.1.3 Pre-charge contactor, Per-charge Resistor and Main contactor:

Precharge circuit consists of Resistor in series with Precharge contactor. Purpose of Precharge circuit is to limit the inrush current flowing into the capacitor. When Capacitor is charged to a desired level as per the feedback taken from voltage sensor, Precharge contactor is opened and main contactor gets closed which is connected parallel across the series combination of precharge resistor and precharge contactor.

Precharge Circuit along with Main Contactor for 50kW DC AC PMFC is shown below:

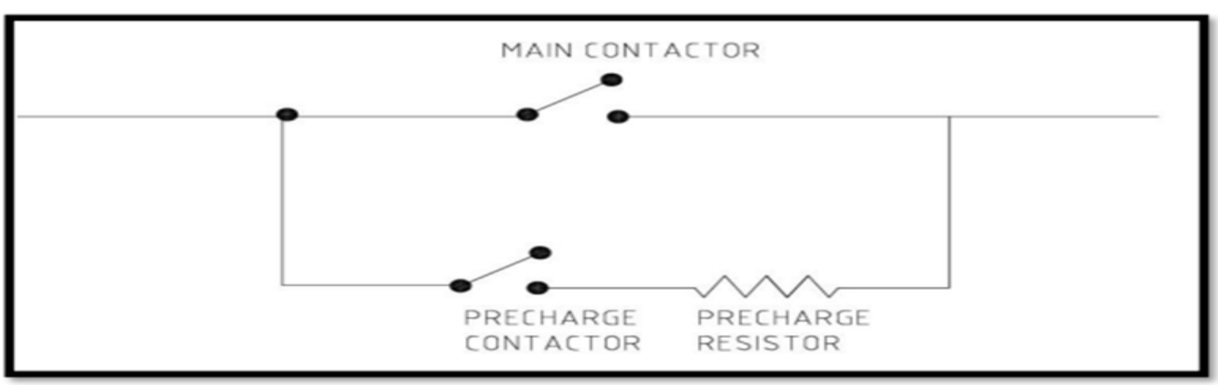


Figure 5.9 Block Diagram of Precharge for Dc-Ac Pmfc

Main Contactor. DC contactor, 400 Amp DC, 400V DC, Control Supply: 24VDC,
Precharge Contactor. DC Relay, 10 Amp DC, 320V DC, Control Supply: 24VDC,
Precharge Resistor: 100 ohms, 200W,
Main Contactor: 3 Pole, 225 Amp (550C), 440V, AC3, Control Voltage: 24V DC
Precharge Contactor: DC Relay, 10 Amp DC, 320V DC, Control Supply: 24VDC
Precharge Resistor: 100 ohms, 200W,

3.3.1.4 Inductor
Inductor of 50kW DC AC PMFC:
In a boost converter, inductor is necessary to achieve a higher voltage on the output than the input. It helps in controlling current ripple and has positive effects on reducing electromagnetic emissions. It also helps in reducing current THD (THD < 2%) at input side.
(a) Inductance Value is 0.5mH
(b) Internal resistance is 12 milli Ohm
(c) Suitable for Switching frequency up to 5kHz
(d) Rated continuous DC current is 180Amp
(e) Short time current is 2 times of rated continuous DC current for 1 sec.
(f) Rated voltage applied to Inductor is 175 V DC to 320 V DC
(g) Maximum voltage applied to the Inductor is 600V DC

3.3.1.5 IGBT based Boost Chopper:
This is the 3 Phase Interleaved boost chopper which boost variable DC input voltage of 175 - 320V DC to 700V DC in 50kW DC AC PMFC. Interleaved boosting concept have been employed to increase the output power and to decrease the input current and output voltage ripples, leading to size reduction of input inductors and output filter capacitor. Compared to the classical boost converter, the interleaved boost converter provides several advantages such as lower input current ripple and output voltage ripple, higher efficiency, lower electromagnetic emission and improved reliability. Higher efficiency is realized by splitting the output current into three paths, substantially reducing inductor AC losses.
The interleaved boost converters consist of several identical boost converters connected in parallel and controlled by the interleaved method which has the same switching frequency and phase shift. Each phase of the interleaved boost converter works in the same way that a single-phase boost converter does. The power stages operate 120 degrees (For 3 phase interleaved boost converter) out of phase, cancelling the ripple current in the input and the output capacitors. The interleaved-boost approach uses forced current-sharing between the power stages to equalize the power that the stages deliver. Due to interleaving operation, interleaved boost converter exhibits both lower current ripple at the input side and lower voltage ripple at the output side. Therefore, the size and losses of the filtering stages can be reduced, and switching losses can be significantly decreased

Details of IGBT Stack
(a) I/P Voltage: 175V DC to 320V DC
(b) Switching frequency of booster chopper -: -- 5KHz
(c) DC link voltage = 700V DC
(d) Power Delivered by the Source: 95kW,
(e) Maximum Rated DC Current delivered by the Source: 543 Amp
(f) DC link capacitor = 10mF
(g) Maximum peak current through each IGBT and Diode may go to up 230Amp for 0.00015sec. This peak repeats after 0.0002 sec for 0.00015sec duration.

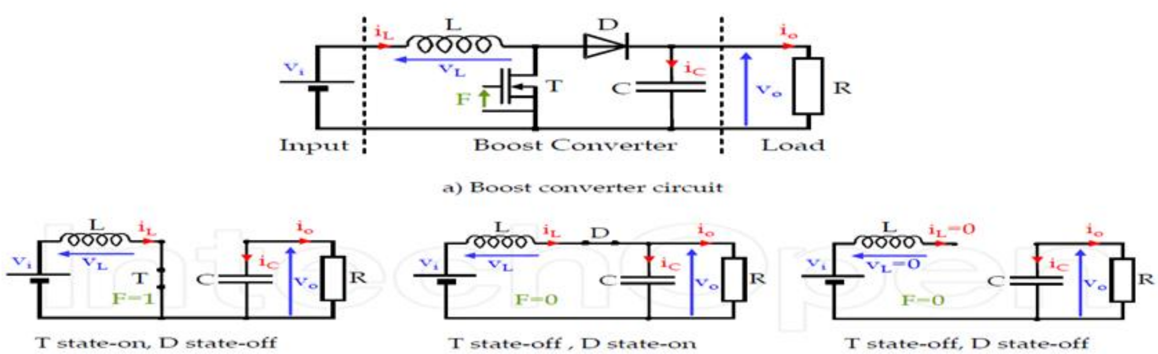


Figure 5.10 Block Diagram of Igbt Based Booster Chopper

3.3.1.6 IGBT based 3-Phase Inverter of 50KW PMFC:
3 phase IGBT inverter is used to convert the constant DC voltage generated by IGBT based Front End Converter to a constant 3 phase AC voltages. The generated 3 phase AC voltage is fed to stator windings of PM motor which drives the motor to a constant speed of 3000 PMFC. Here the 3 phase IGBT inverter generates 330V (L-L), 200Hz 3 phase AC voltage which is fed to 8 pole PM motor. The resultant speed of the motor is 3000 PMFC. The inverter consists of IGBTs which are required to be switch on and off by pulse width modulated signals (PWM) to generate the required voltage at inverter output.

I/P to inverter: 700V DC in case of DC-AC PMFC
O/P of Inverter is 330V, 200Hz.
Details of IGBT Stack:
(a) Switching frequency of 3 phase inverter = 5 KHz
(b) Power taken by permanent magnet synchronous motor = 85kW (rated power of motor). This is maximum continuous power.
(c) Line to line voltage obtained by 3 phase inverters = 330V rms, 200Hz (rated voltage of the motor).
(d) Rated line current taken by permanent magnet synchronous motor through Inverter is 175 Amp rms, 200 Hz at 0.85 power factor.

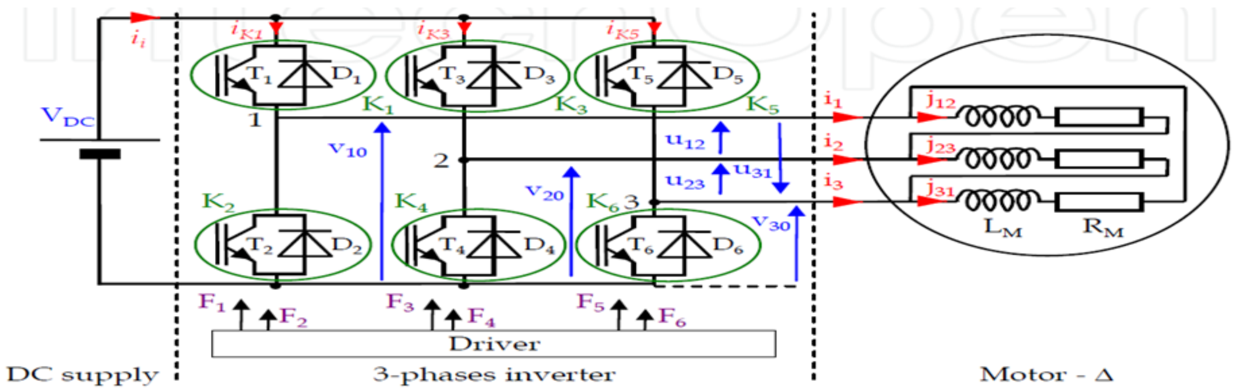


Figure 5.11 Block Diagram of Igbt Based 3phase Inverter

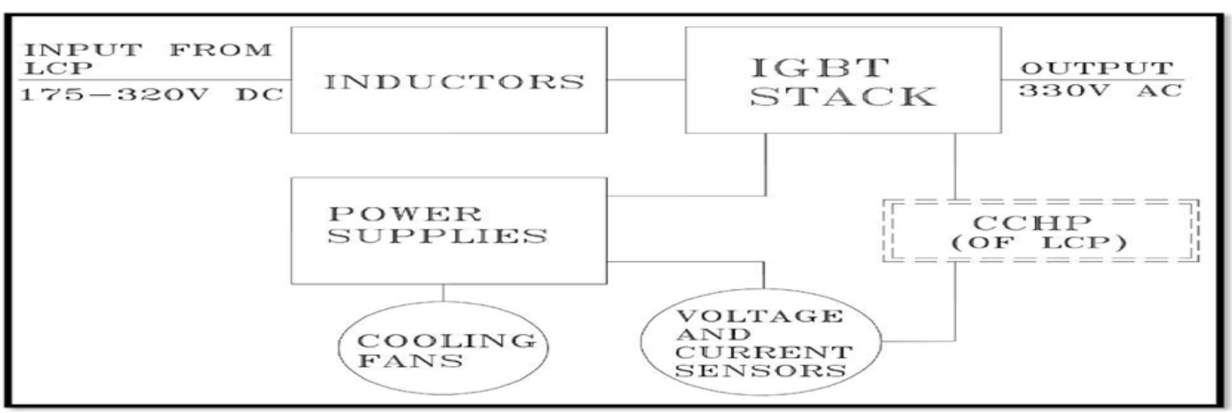


Figure 5.12 Functional Block Diagram of Inverter Unit

3.3.1.7 Voltage and Current Sensors:
Voltage Sensors are used for measuring Input DC supply voltage, DC link voltage and output voltage of Inverter. Current Sensors are used for measuring current at Input of Interleaved Boost Chopper and output of Inverter.

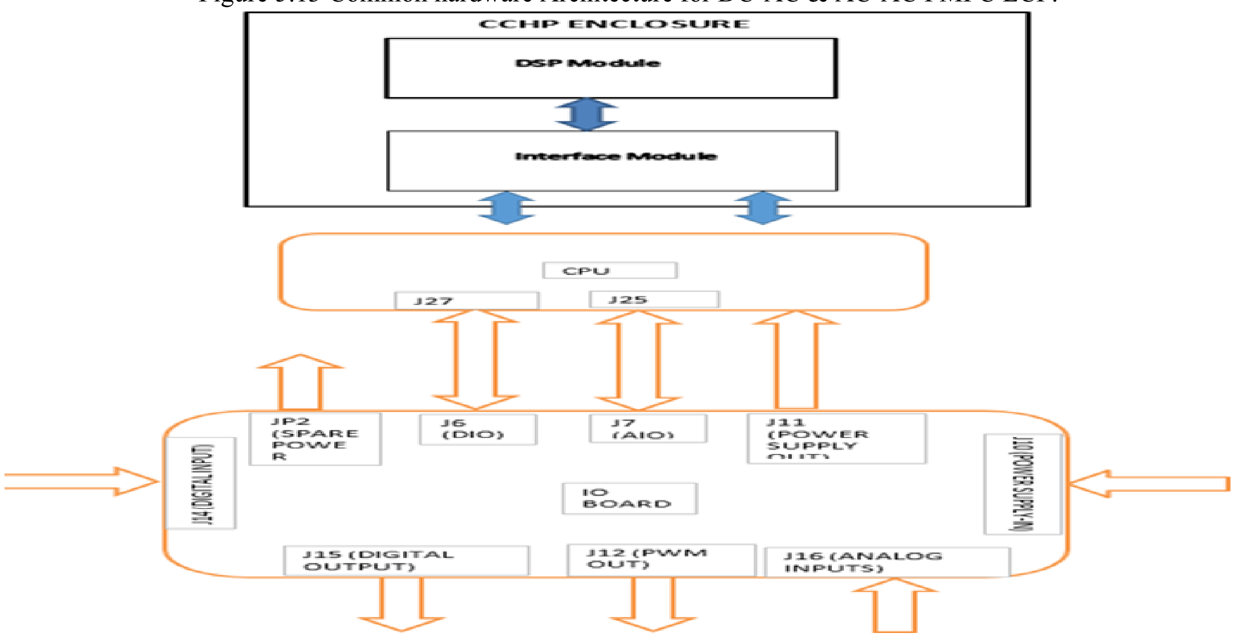
- LEM make Voltage sensor DVL 500 is used for measuring Input DC supply voltage and output voltage of Inverter.
- LEM make Voltage sensor DVL 1000 is used for measuring DC link voltage. Output of both Voltage sensors is from 0 to 50mA which goes to Analog Signal Conditioning Circuit of Interface Board.

- LEM make Current sensor LTC 600-T/SP16 is used for measuring current at Input of Interleaved Boost Chopper. Its output is from 0 to 120mA which goes to Analog Signal Conditioning Circuit of Interface Board.
- LEM make Current sensor LF205-S/SP1 is used for measuring Inverter Output current and Current at input of Front-End Converter. Its output is from 0 to 100mA which goes to Analog Signal Conditioning Circuit of Interface Board.

3.3.1.9 DSP+FPGA Board along with Interface board: This section describes the hardware features of the board, including the detailed pin-out and component reference information that interface with all components of the board.

DSP Based Hardware (CCHP):
DSP based hardware (Common Control Hardware Platform (CCHP)) consists of a DSP module and an Interface module housed inside a single mechanical enclosure.
Main CORE of the board is DSP SM320F28335 and Altera® Cyclone® V SoC. Altera Cyclone V SoC, which includes the Hard Processor System (HPS) with integrated ARM® Cortex™-A9MPCore processor

Figure 5.13 Common hardware Architecture for DC-AC & AC-AC PMFC LCP:



3.3.2 Hardware Design of Pmfc:

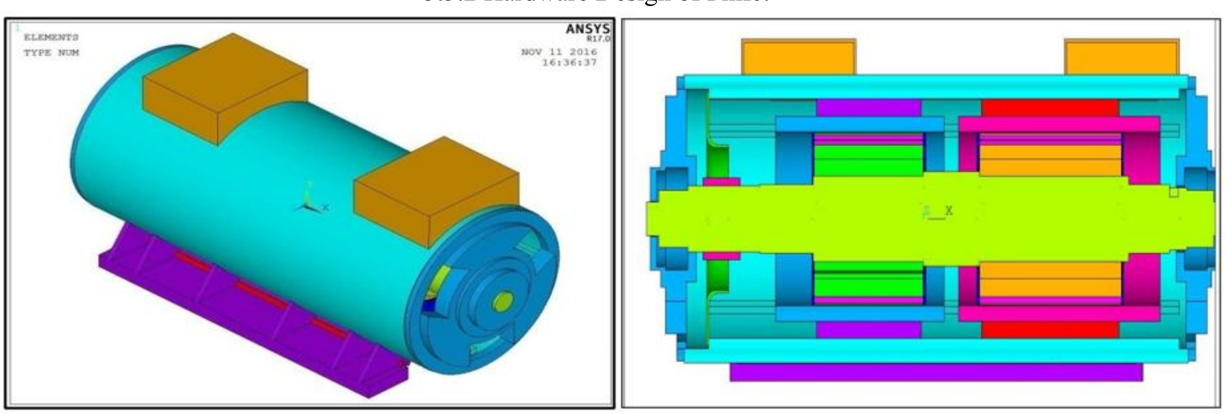


Figure 5.14 Isometric View of Pmrfc & Longitudinal Section View of Pmrfc Design sheet of PMFC: Motor rating: 50 kW, 330V, 3000 PMFC, 400Hz

3.3.2.1 Stator dimensions and details:

Motor	Generator
a) Da = 420 mm, Di = 306 mm, L = 280 mm	a) Da = 420 mm, Di = 306 mm, L = 208 mm
b) No. of Slots = 72	b) No. of Slots = 72
c) No. of Turns/coil= 1	c) No. of Turns/coil= 1
d) No. of coils / slot = 2	d) No. of coils / slot = 2
e) No. of parallel paths = 2	e) No. of parallel paths = 2
f) No of poles =8	f) No of poles =16
g) Winding – Mush Type	g) Winding – Mush Type
h) Air gap = 2.5 mm	h) Air gap = 2.5 mm
i) Stator current in normal load= 127 A	i) Stator current in normal load = 157 A

3.3.2.2 Rotor dimensions and details:

Motor	Generator
a) OD = 301 mm, ID = 150 mm, L = 310 mm,	a) OD = 301 mm, ID = 150 mm, L=226 mm,
b) No. of poles = 8	b) No. of poles = 16
c) Rotor moment of inertia: 3.5 kg-m2	c) Rotor moment of inertia: 3.5 kg-m2
d) Flux per pole Phi = 25.6 X 10 -3 wb	d) Flux per pole Phi = 25.6 X 10 -3 wb

3.3.2.4 Various Design Aspects of PMFC:

3.3.2.4.1 Electromagnetic Analysis:

a) In a conventional machine the magnetic field in the air-gap is created by current passing through field coils. However, in Permanent Magnet Machines, the Permanent Magnets mounted on the rotor create the magnetic field. The design of permanent magnet motor-generator set differs from the design of a conventional MG set. The Permanent Magnet not only supplies the no-load flux but also takes care of armature reaction effect. The drop in PMG output voltage (during loading) should be such that the voltage variations meet the specification set for the machine. Design procedure followed in this case is based on analysis made using different software like MAGNET, JMAG etc.

b) Electro Magnetic design will be carried out by

- Analytical approach.
- Available machine design program by SIEMENS for synchronous machines
- Using SPEED software
- Validation by MAGNET/MAXWELL/ JAMG for 2D and 3D analysis.

c) The solution approach is based on the highly accurate finite element method for simulating static, frequency dependent or time varying electromagnetic fields

d) Machine up to 100 kW is generally designed with more no. of poles (eg. 16 Poles) because of convenience of fitment of magnets on the rotor.

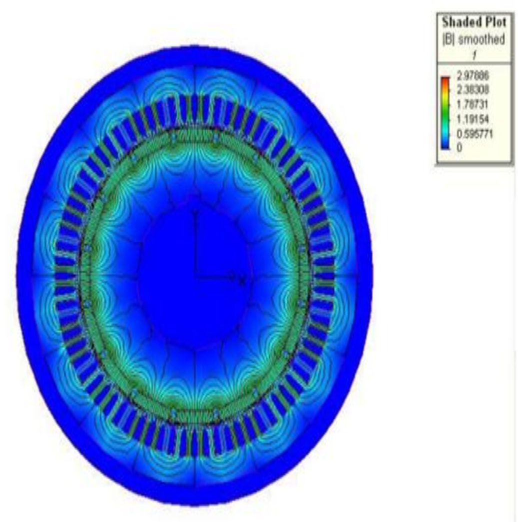


Figure 5.15 Flux plot in MAGNET software

3.3.2.4.2 Specifications of NdFeB Magnets:

- Remanence Br. (Gauss) = 11.6 -12.0 kG
- Coercivity (Oersted) = 10.6-11.0 kOe
- BH Max (Mega Gauss Oersted) = 34 – 35 MGOe
- Temperature Class = 230 °C
- Temperature Coefficient ` = 0.08-0.09 %

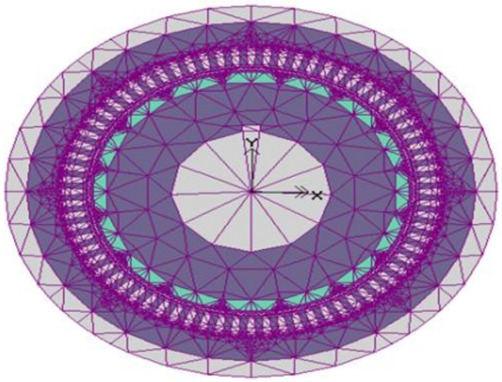


Figure 5.16 FE model for analysis in MAGNET software

3.3.2.5 Pmsm Construction Details:

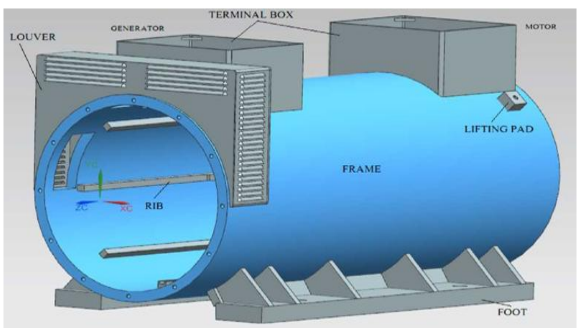


Figure 5.17 General view of PMRFC STATOR

Pmsm Rotor Hum (Motor-Generator):

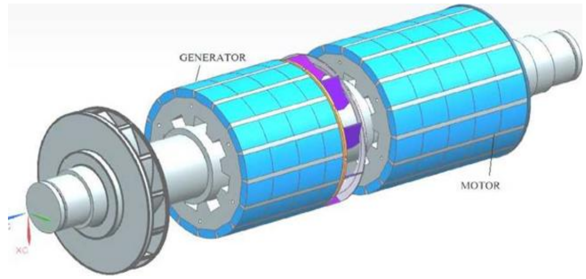


Figure 5.18 general view of Rotor Hum Motor – Generator

Stator Winding (Motor Vs Generator):

3.3.3 Pmsm Vector Control Method:

The supply source of PMSM is a DC link which could be derived from battery or a rectified ac supply. A two-level VSI implemented using IGBT is used to convert DC to AC at required voltage and frequency. Output of the inverter will be Pulse Width Modulated (PWM) signals who's fundamental will be a sinusoidal AC, which is supplied to the PMSM. This will be sufficient for normal operation of the drive, because the motor will itself act as a low pass filter and take only sinusoidal currents.

The sensor less control algorithm uses the reference and sensed signal to provide appropriate gate signals to achieve a good dynamic performance of the drive.

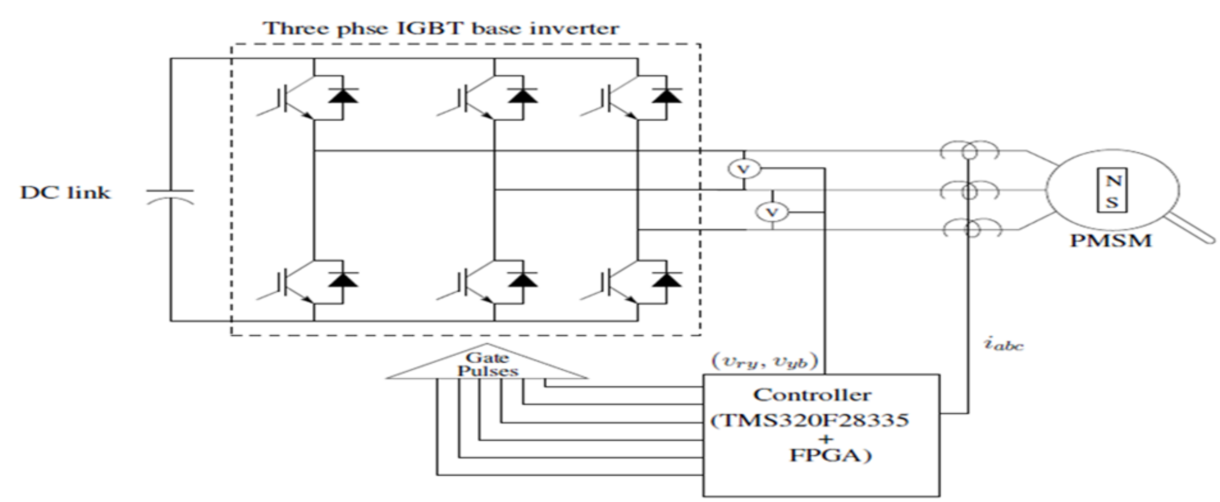


Figure 5.19 Power circuit diagram of PMSM drive

Sensor less Vector Control of PMSM Drive:

Use of Speed sensor increases cost and reduces robustness and reliability of the machine. In some cases, it may be difficult to employ speed sensor on the shaft of the machine due to mechanical constraint. It is also difficult to run cables from machine to the controller, if the machine is located at a remote location.

Because of these reasons Vector control method mainly consists of three steps:

1. Speed ramp-up using I-f method
2. Stopping of pulses for position estimation
3. Sensorless vector control
1. Initial frequency ramp-up (I-f starting): Initially the stator current frequency is increased linearly from 0-10Hz.

$$f^* = kt$$

$$\theta_{crt} = \int 2\pi f dt$$

2. Stopping of pulses for position estimation: Supply to the machine is cut-off by stopping the pulses for small time (approx. for 100µSec) of the Inverter.

a. During the pulse turn off time, induced line to line voltage of the motor are measured using two voltage sensors to measure the instantaneous line voltage.

The Voltage equation is $v = \frac{d\varphi}{dt}$

b. Sinθemf and Cos θemf are estimated:

$$\sin(\theta_{emf}) = \sin(\theta - 120) = \sin\theta\cos 120 - \cos\theta\sin 120$$

$$= -0.5(\sin\theta + \sqrt{3}\cos\theta)$$

$$\cos(\theta_{emf}) = \cos(\theta - 120) = \cos\theta\cos 120 - \sin\theta\sin 120$$

$$= 0.5(\sqrt{3}\sin\theta - \cos\theta)$$

$$\omega_e = \frac{d\theta}{dt}$$

c. Speed Estimation for Sensor less vector control:

$$\omega_{emf} = \cos\theta_{emf}\frac{d}{dt}(\sin\theta_{emf}) + \sin\theta_{emf}\frac{d}{dt}(\cos\theta_{emf})$$

3. Switching over to Sensorless Control:

Once the Rotor position is estimated accurately during pulse turn off, the motor control can be switched to sensorless control. Now the PMSM motor operates in Sensorless control mode with speed controller in the outer loop and current controllers in the inner loop.

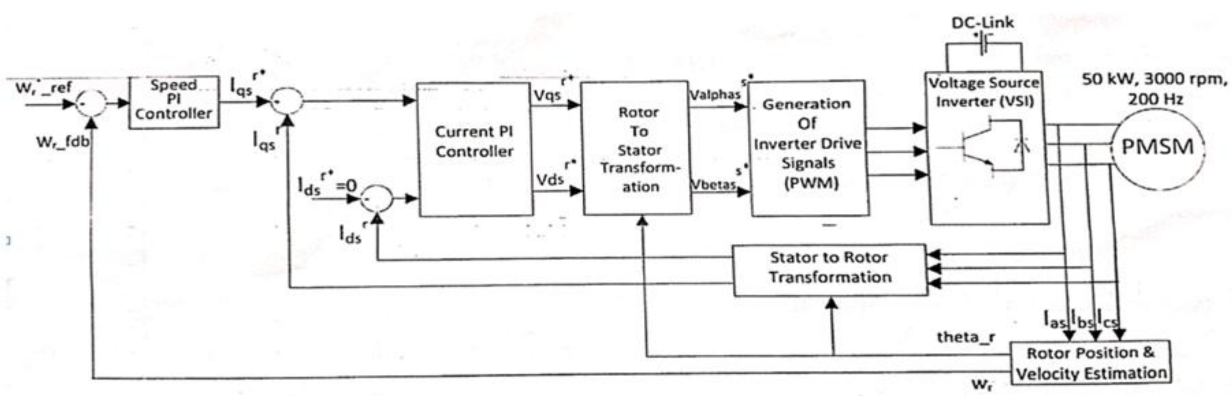


Figure 5.20 Block diagram of Sensorless Vector Control scheme of PMSM drive

The three phase currents (ir, iy,ib) of the Inverter from three current sensors will be taken and converter into iα and iβ using Clarke transformation. iα and iβ will be resolved into i_{sd} and I_{sq} along the d-axis and q-axis respectively. Since i_{sd} and I_{sq} moves in the space at synchronous speed at steady state, i_{sd} and I_{sq} will be constants. By controlling i_{sd} and I_{sq}, we can control torque and flux of the machine independently. Thus, using vector control the input stator current is resolved into torque producing component and flux component. In Sensorless vector control the Rotor flux position estimation and speed estimation is critical in field-oriented control. The performance of drive depends on the accuracy of estimation. In speed Sensorless control, the stator flux is estimated using stator voltage integration method. The position of rotor flux is calculated thereafter. This will give rotor position transformation and differentiation of rotor position gives rotor speed. To avoid problems due to DC offset a low pass filter is used instead of a pure integrator.

IV. MODELLING & ANALYSIS OF DC-AC HYBRID CONVERTER

4.1 Practical Experiment of Boost Chopper

To prove the Booster philosophy experiment for boosting the voltage from 83.6 V to 430 V DC is carried out. For experiment inductor parameters are 0.35 mH, 0.03 Ohm, DC link capacitor 0.5 mF and load resistance 400 Ohm, 2 kW. The actual pictures of test set up and readings are given in fig 6.1. The control loop simulated as per fig 6.2 is used in practical experiment also with single inductor. The result obtained in simulation and practical experiment is similar and is as expected. To achieve desire DC link voltage, feedback of input current and output DC link voltage is taken through transducers in controller for controlling the duty cycle of IGBT with range from 0 to 75%.

Figure 6.1 Photo of Lab Setup for Booster Chopper

Figure 6.1 Photo of Lab Setup for Booster Chopper

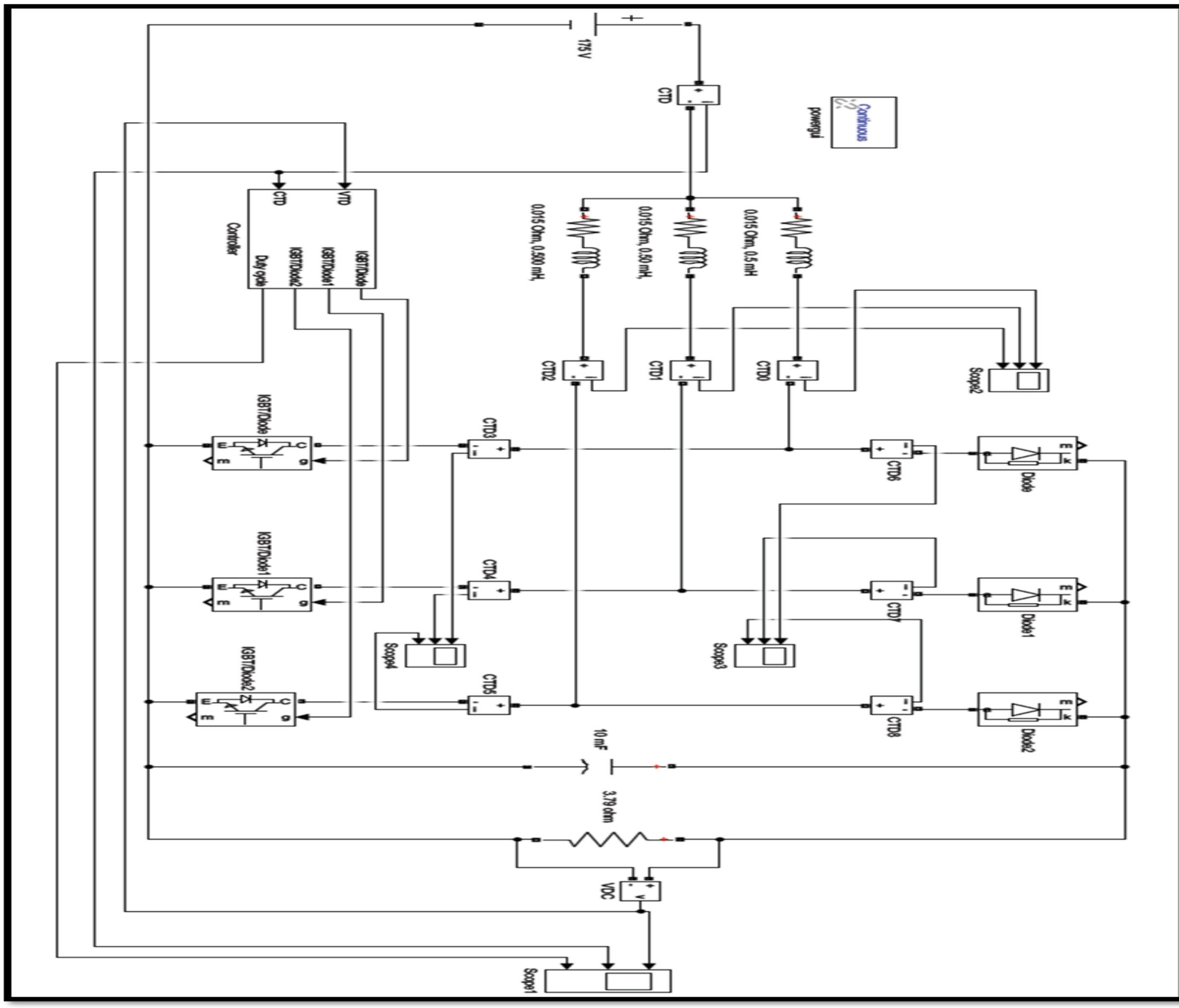


Figure 6.2 Matlab Simulation Model of Interleaved Boost Converter

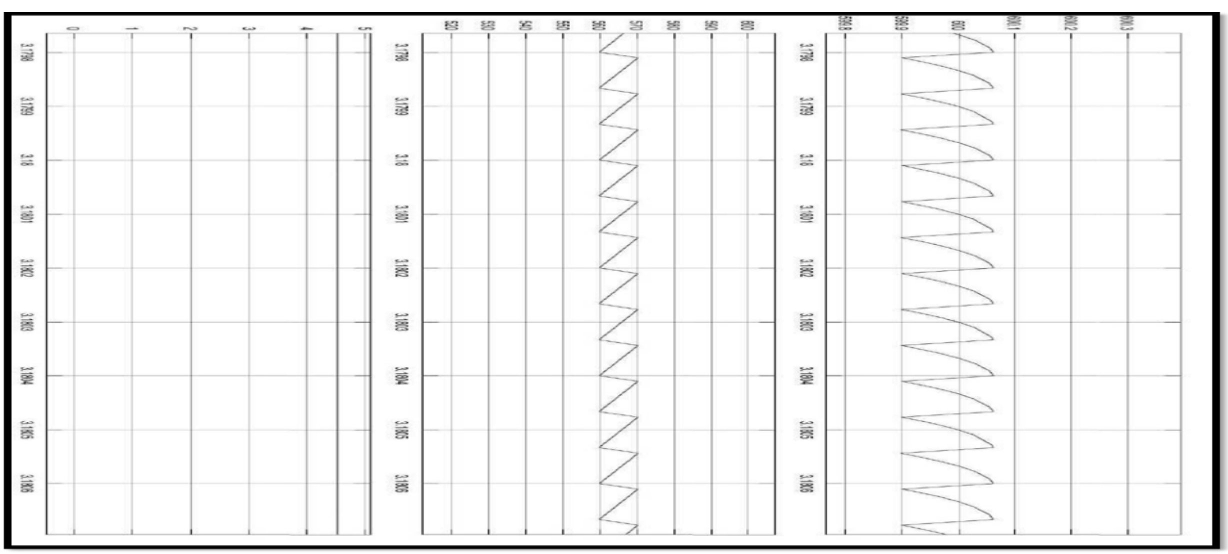


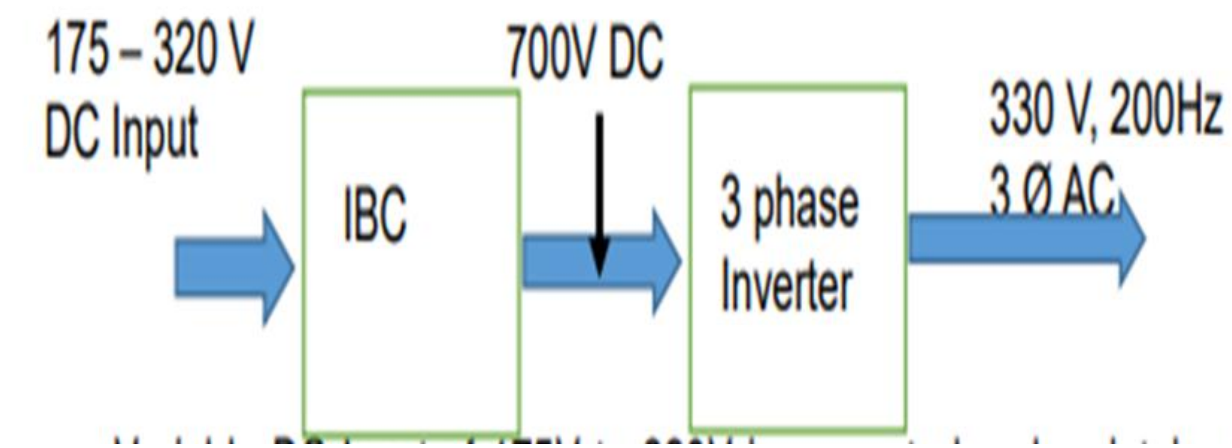
Figure 6.3 Matlab Simulation Results (Output Voltage and Input Current and Duty Cycle of Interleaved Boost Chopper)

Simulation Results for Boost Converter:
1) Input current ripple at any battery voltage < 2 %
2) DC link voltage ripple at any battery voltage < 0.5 %

Advantages of interleaved boost converter over simple boost converter
1. Reduction in input current ripple
2. Reduction in output voltage ripple
3. Better EMI performance
4. Increase in reliability
5. Better dynamic performance

For the boost stage of 50kW DC-AC PMFC, three phase interleaved boost converter is selected.

Effect of variations in Input DC supply voltage on DC-AC PMFC System:



Variable DC Input of 175V to 320V is converted and maintained to a constant DC by Interleaved Boost Chopper (IBC). IBC is designed for 95 kW power rating for input voltage range 175-320V DC. For 50 kW load, power delivered by source is 62 kW taking Machine efficiency 90% and IGBT stacks efficiency 90%. Current flowing at 175 V DC through Interleaved Boost Chopper is 355 Amps which is well within IGBT stack rating.As the inverter gets constant DC there will be no effect of input variations at output.Control power supplies (SMPS) are designed to accept the variable input of 175V to 320V DC, hence no effect on control operations.

4.2 Matlab Simulation to Complete System & Results:

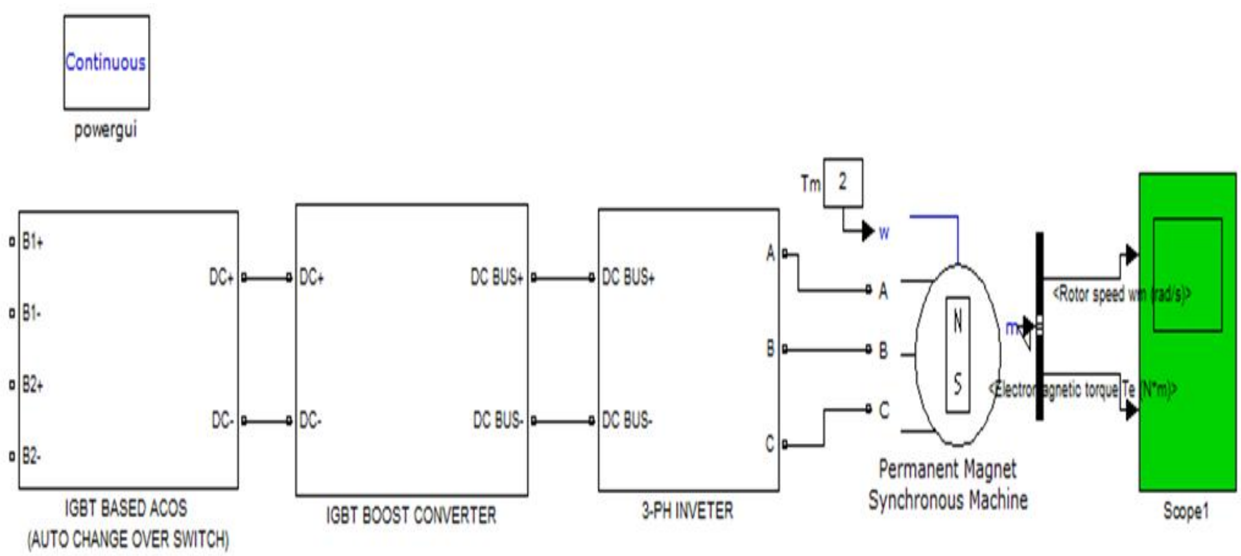
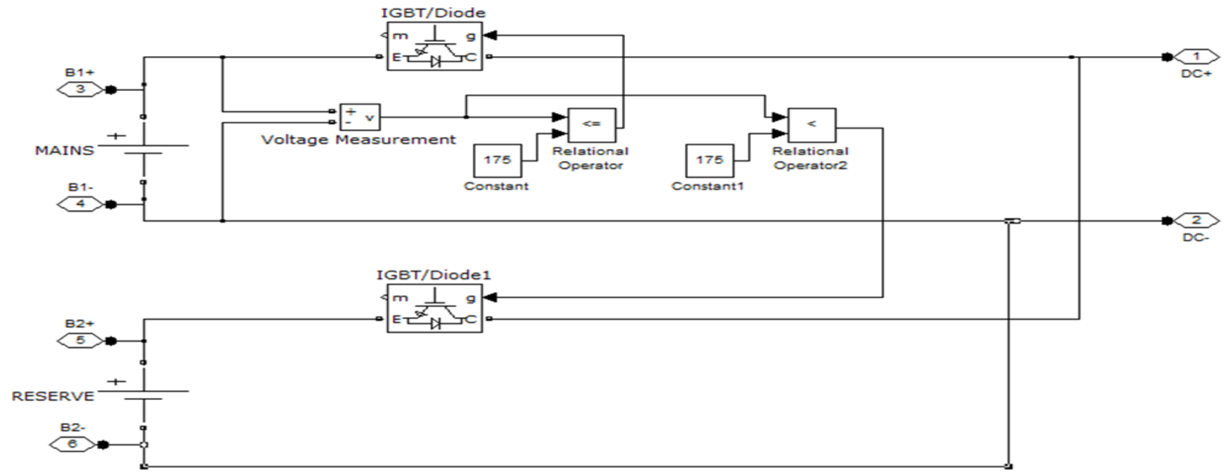
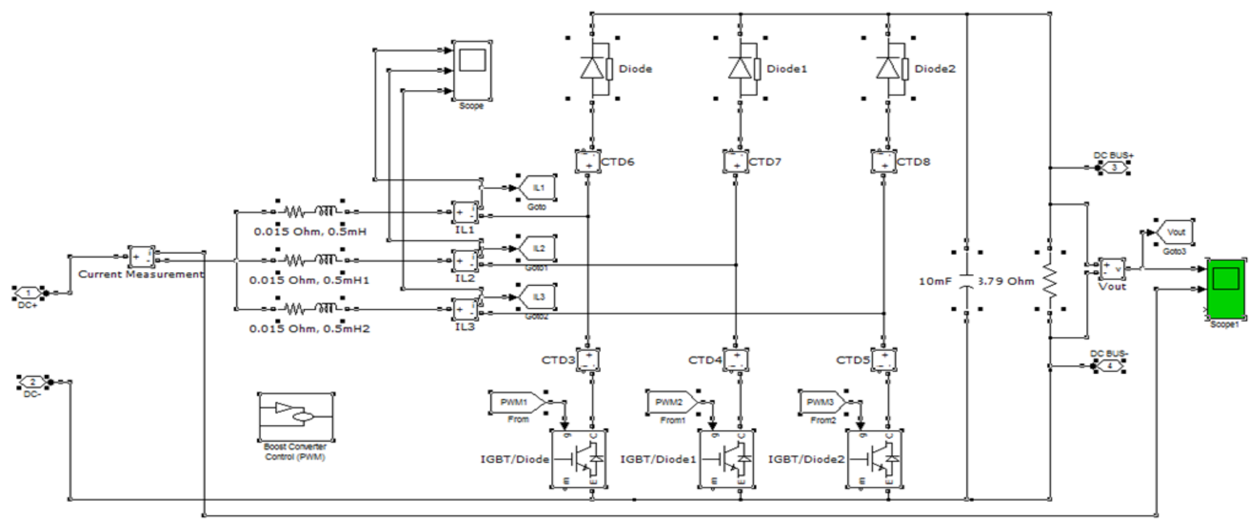


Figure 6.4 Matlab Simulation Circuit of Hybrid Converter

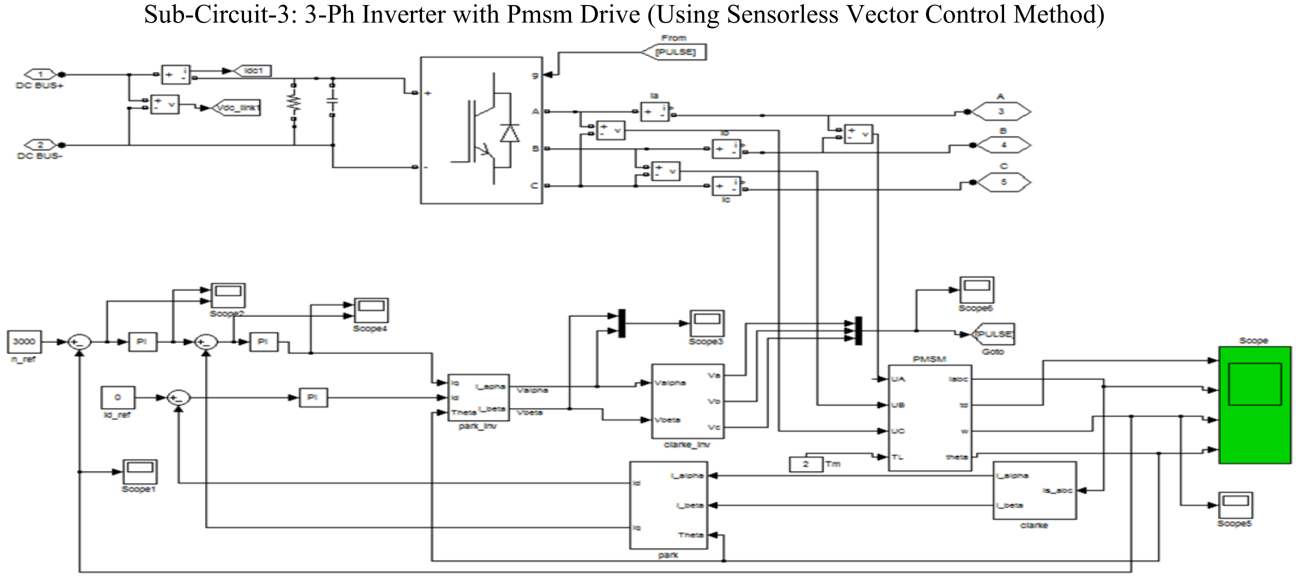
Sub-Circuit-1: Igbt Based Acos (Auto Change Over Switch)



Sub-Circuit-2: Igbt Based Interleaved Boost Converter

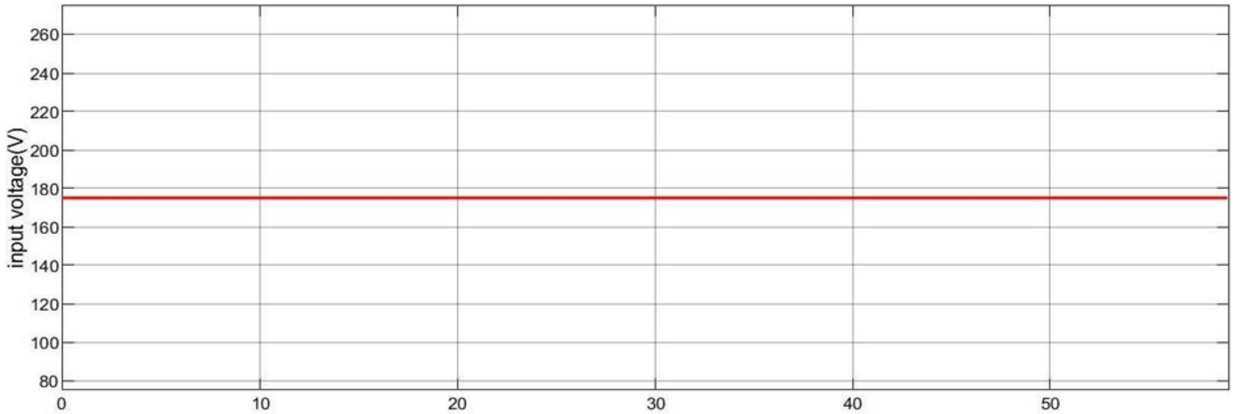


Sub-Circuit-3: 3-Ph Inverter with Pmsm Drive (Using Sensorless Vector Control Method)

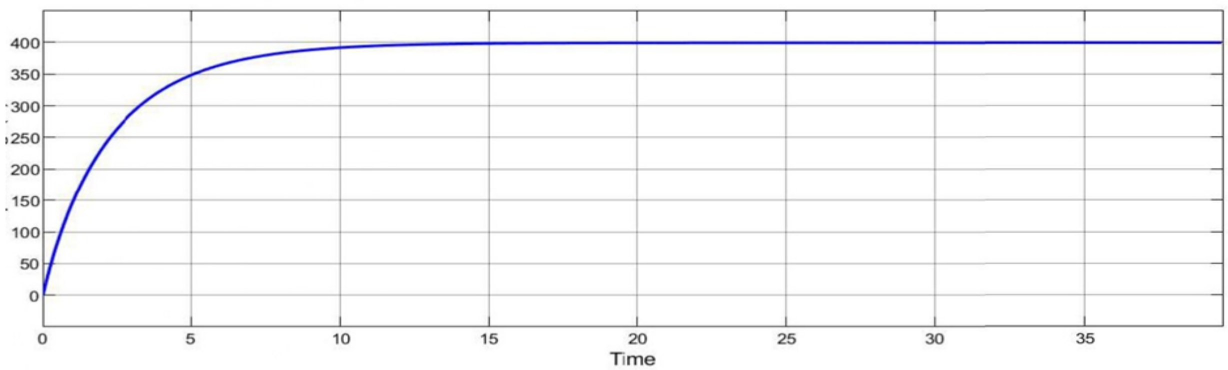


V. MATLAB SIMULATION RESULTS

Case-1: At the Input of 175V DC, the output obtained is 230V, 3Ph, 400Hz and waveforms obtained from MATLAB during simulation are shown in Fig 6.5



Waveforms Obtained from MATLAB at Input 175V DC From Battery



Waveforms Obtained from MATLAB-Boost Converter Output is 400V DC at Input 175V DC

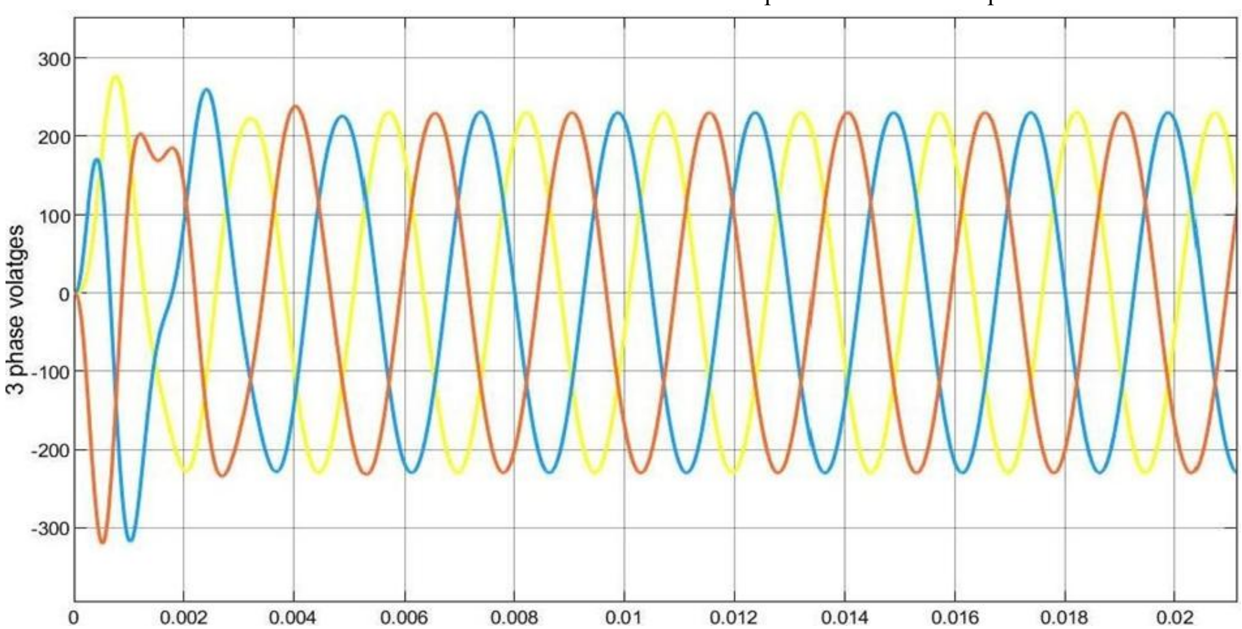
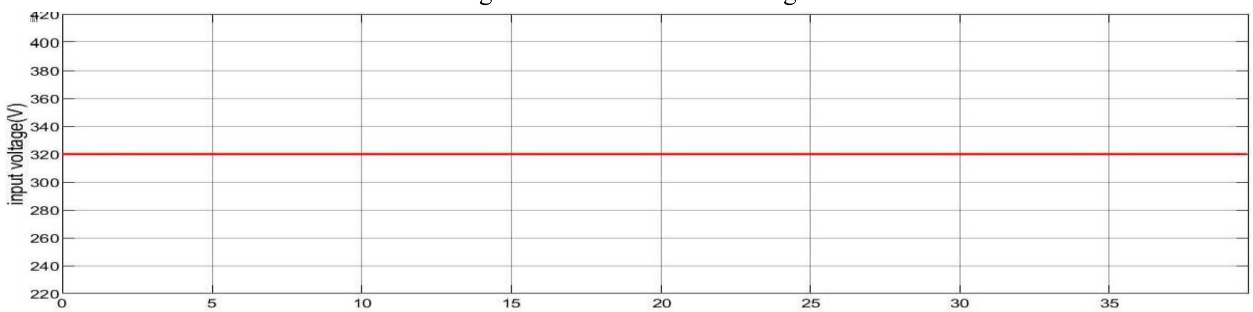
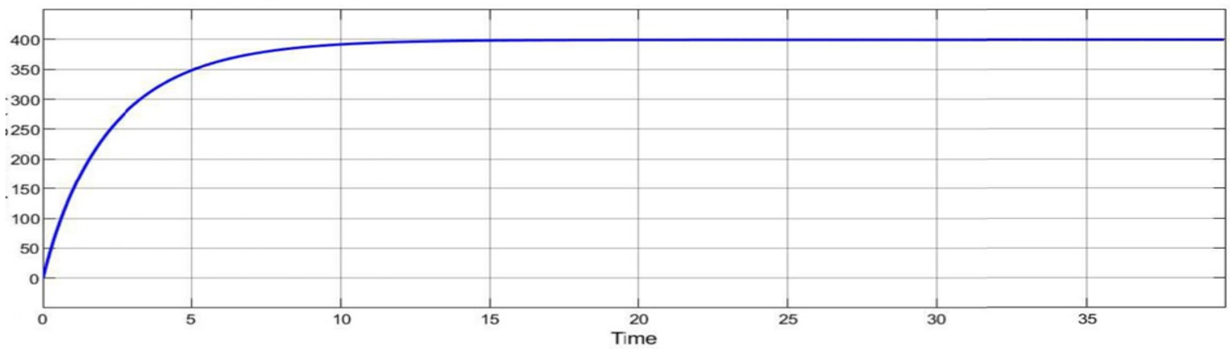


Figure 6.5 Waveforms from MATLAB–Hybrid Converter Output is 230V, 3Ph, 400Hz at Input 175V DC

Case-2: At the Input of 320V, the output obtained is 230V, 3Ph, 400Hz and waveforms obtained from MATLAB during simulation are shown in Fig 6.6



Waveforms Obtained from MATLAB at Input 320V DC From Battery



Waveforms Obtained from MATLAB-Boost Converter Output is 400V DC at Input 320V DC

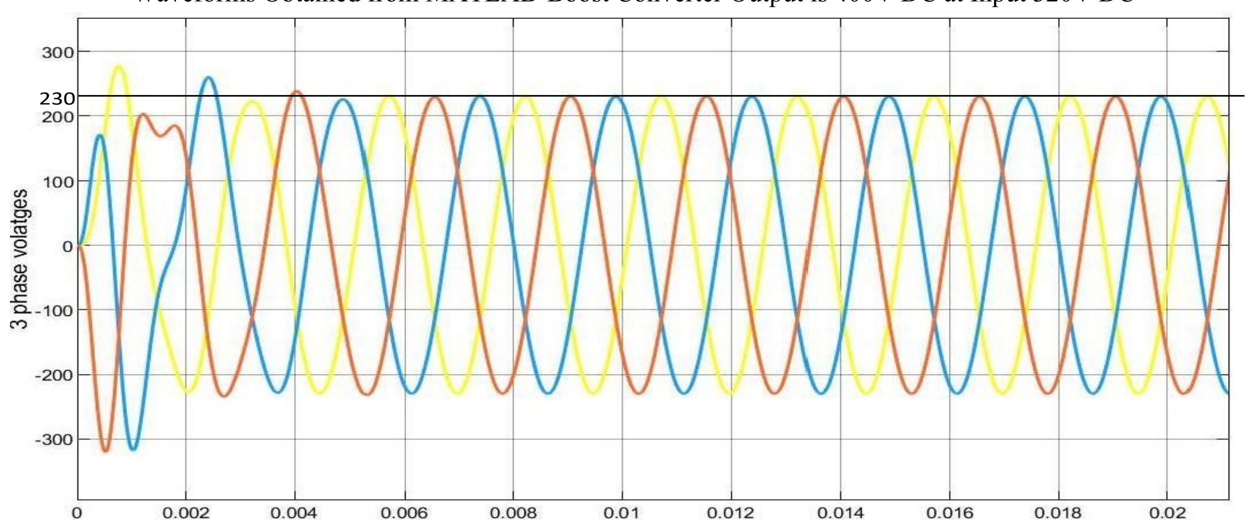


Figure 6.6 Waveforms from MATLAB–Hybrid Converter Output is 230V, 3Ph, 400Hz at Input 320V DC

Calculation of Hybrid Converter Output Frequency:
Frequency, f=1/t
Where, f = Frequency t = Time period
Therefore, the frequency, f = 4*1/t = 4*1/0.01= 400Hz.

By Considering the Yellow phase wave form in Hybrid converter output shown in Fig 6.5 or Fig 6.6, it takes 04 cycles during a time period of 0.01 Sec.

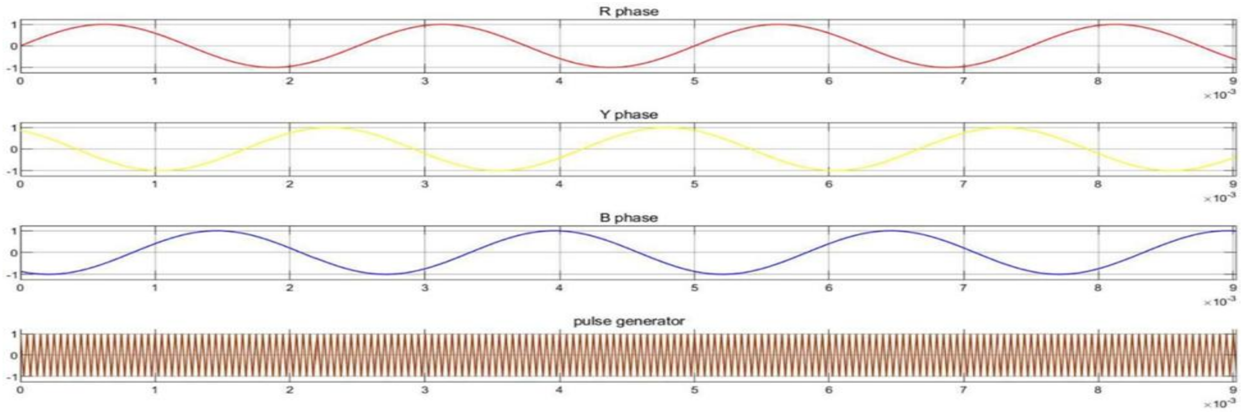


Figure 6.7 Waveform-MATLAB at Input RYB Sinusoidal &Pulse Generator for PWM

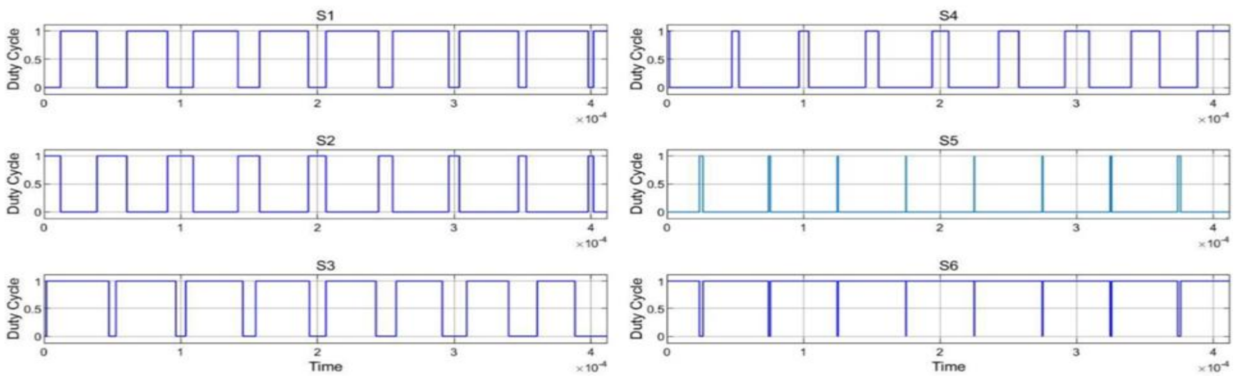


Figure 6.8 Waveforms from MATLAB for Duty cycle

5.1 Loss Calculation Of 50 Kw Dc-Ac Pmfc:

(i) Loss calculation in Inductor

Inductor internal resistance: - 5 mOhm,

Maximum current through inductor: - 190 Amp DC

Maximum Copper losses in inductor: - 190*190*0.005 = 180.5 W

Total Copper loss in Inductor unit: - 3*180.5 = 541.5 W

Total iron loss in inductor unit: - 45*3 = 135 W

Total loss in Inductor unit: - 676.5 W

(ii) Losses in Booster:

Total Conduction loss in IGBTs: 3*200*2.2*0.000142/0.0002=937.2 W

Total Switching loss in IGBTs: - 774 W

Total Conduction loss in all Diodes: - 200*2*3*0.00006/0.0002 = 360 W

Total Switching loss in all Diodes: - 250 W

Total combined loss in Booster: - 2321.2 W

(iii) Losses in Inverter:

Conduction loss in IGBT: - 88 W

Switching loss in IGBT: - 93 W

Conduction loss in Diode: - 33 W

Switching loss in Diode: - 34 W

Total combined loss in IGBT and Diode: - 248 W

Total loss in Inverter: - 248*6 = 1488 W

Losses in 500 V sensors (7 nos): - 0.2*7 = 1.4 W

Loss in 700 V sensors (1 nos): - 0.2*1 = 0.2 W

Losses in current sensors (3 nos): - 0.245*3 = 0.735 W

Losses in 600-amp current sensors (1 nos): - 0.3 W

Losses in Power supplies (7 nos): - 145 W

Losses in DSP and I/O cards: - 30 W

Losses in Contactors, Relays, EMI Filter and other small devices: -170W

5.2 Frequency Dip During Changeover:

DC link voltage – 750VDC

DC link Capacitor – 10mf

Energy stored in Capacitor = 1/2x 10x 10-3 x 750 x 750 = 2812.5 joule

When DC link voltage – 600VDC

Energy stored in Capacitor = ½ x10-3 x 10 x 600 x 600 = 360 x 5 = 1800 joule

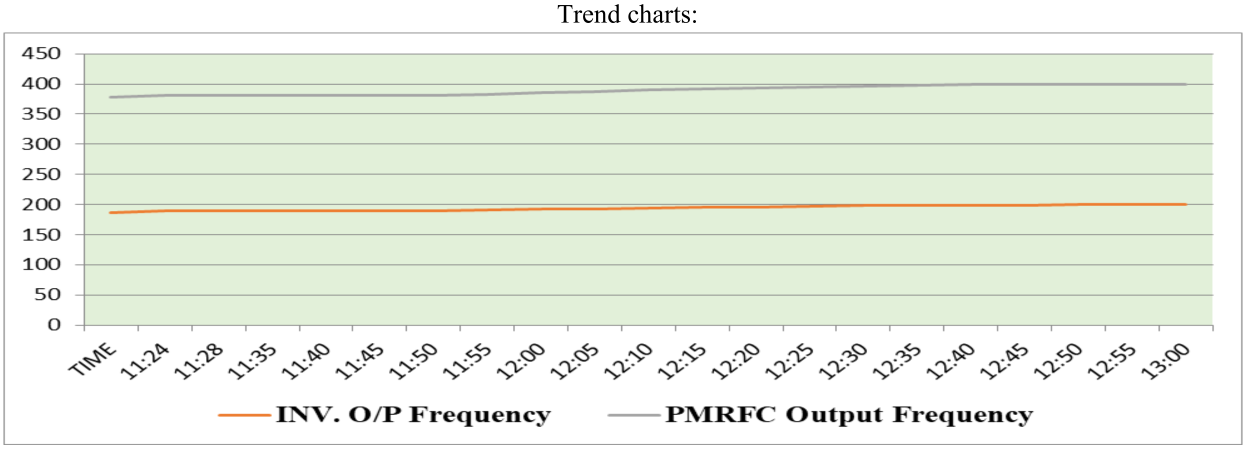
Net energy transferred by Capacitor during this process = 2812.5 -1800 = 1012.5 joule

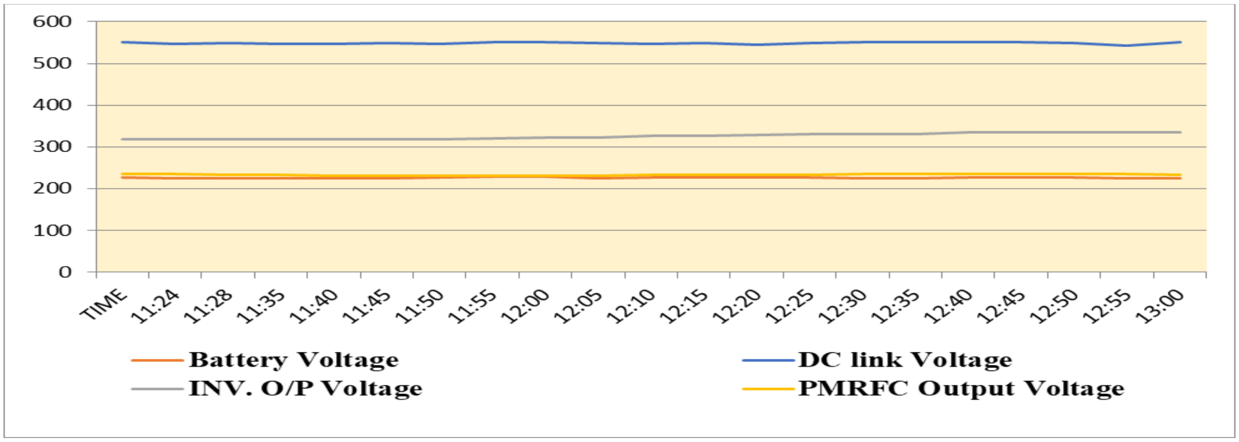
Power delivered by DC link Capacitor is $(50x10^3)/(0.95x0.95x0.95)$ = 58.32 kW
Let DC link Capacitor delivered this much power for t sec. Then $58.32x10^3$ x t = 1012.5 t = 17.36 msec.
Moment of inertia of system = 3.5kg m^2
Angular velocity = 3000 PMFC = 3000 x 2π/60 = 314.16 rad/sec
Mechanical energy stored = ½ x 3.5 x 314.16 x 314.16 = 172.72 kJ
Power delivered by system = 50 x 10^3W
Energy delivered in 80msec = 50 x 10^3 x 0.08 Joule = 4 kJ
Remaining Mechanical energy stored = (172.72 - 4) kJ = 168.72 kJ
W is the angular velocity at which Mechanical Energy stored is ½ 3.5 x W^2 = 168720 W = √96411.43 = 310.5 rad/sec
Frequency = 310.5 x 60 x 16 / 2π x120 = 395.34 Hz.
Frequency dip in 97.36 msec is 4.66 Hz.

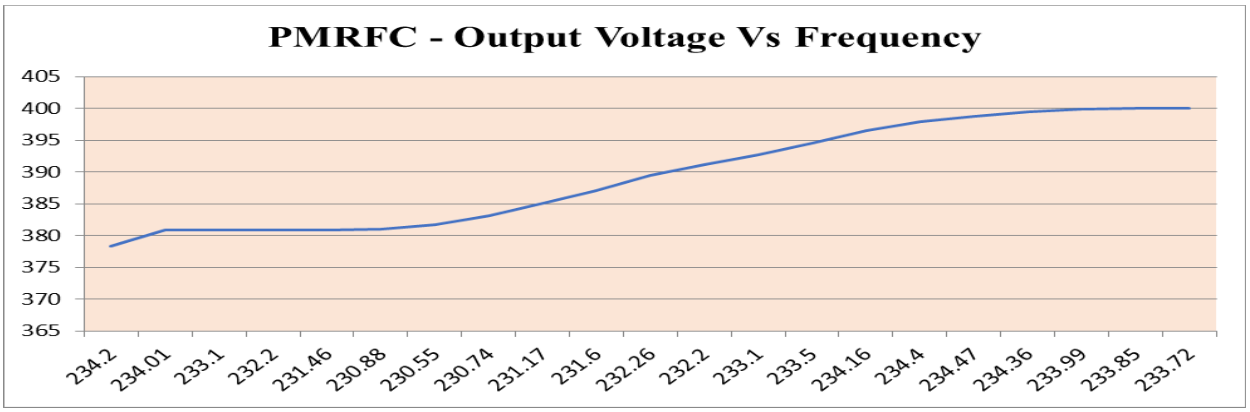
6.6 Load trials of DC-AC PMRFC

TIME	Battery Voltage	Input Current	DC link Voltage	INV. Output Voltage	INV. Output Frequency	LOAD (KW)	PMRFC Output Voltage	PMRFC Output Frequency
11:24	226	146	551	318	186	15	234.2	378.3
11:28	224	144	546	318	190	15	234.01	380.91
11:35	224	145	549	318	190	15	233.1	380.92
11:40	224	153	547	318	190	15	232.2	380.92
11:45	224	149	547	318	190	15	231.46	380.94
11:50	224	150	549	318	190	15	230.88	381.02
11:55	227	149	547	319	190	15	230.55	381.69
12:00	228	141	550	320	191	15	230.74	383.12
12:05	228	153	550	322	192	15	231.17	385.06
12:10	224	142	548	323	192	15	231.6	387.01
12:15	226	143	547	326	194	15	232.26	389.4
12:20	227	141	549	327	195	15	232.2	391.1
12:25	227	143	544	328	196	15	233.1	392.7
12:30	227	153	549	330	197	15	233.5	394.5
12:35	224	141	551	331	198	15	234.16	396.5
12:40	225	143	552	331	198	15	234.4	397.9
12:45	226	144	551	334	199	15	234.47	398.7
12:50	226	143	550	334	199	15	234.36	399.5
12:55	226	142	549	334	200	15	233.99	399.82
13:00	225	150	543	334	200	15	233.85	399.96
13:05	225	149	550	335	200	15	233.72	400

Trend charts:







VI. CONCLUSION

6.1 Conclusion:

6.1.1 Case Study on DC-AC 400Hz Rotary Converter (Russian made) installed onboard underwater marine platforms, gave an opportunity to understand its installation and maintenance aspects of Rotary machines. During study, the various defects observed have been completely analyzed and addressed with a suitable solution. Understand the challenges involved in spare parts management during repairs view imported. & compatibility issue of components with other On-board available AC-AC Rotary Frequency converters.

6.1.2 Therefore, the complete project focused on Homogenization of machine components with Indigenized technology to improve system reliability. Here Design a Hybrid converter (Rotary converter with advent power electronic static device) for control of Non-linear loads:

1. ACOS (Auto Change over Switch): IGBT based switches between mains & Reserve supply based on their voltage levels within 40µSec & improves the system stability.
2. IGBT based Interleaved Boost Converter: Employed to increase the output power and to decrease the input current and output voltage ripples, leading to size reduction of input inductors and output filter capacitor. Maintaining const. DC bus voltage before the Inverter, which provide a stable and reducing stress on the final conversion stage.
3. IGBT based 3-Phase Inverter for PMFC: 50% frequency up-gradation (DC - AC, 3Ph, 200HZ) by static converter using PWM controlled IGBT Inverter, which minimizes the Rotary Converter size. And this unit is Homogeneous for both DC-AC and AC-AC converters, which improve the system reliability.
4. Permanent Magnet Rotary Converter: It gives Harmonic free, pure sinusoidal wave form output. And this unit is Homogeneous for both DC-AC and AC-AC converters, which improve the system reliability. Voltage harmonics in Rotary PMFC is 0.5% where in Static PMFC is 2%. Hence it is recommending for Hybrid converter only for Ships & Submarines applications to meet their critical operations.

REFERENCES

[1] P.S. Bimra: „Power electronics" (KANNA PUBLISHERS, 2004)
[2] Nead Mohan: „Power electronics" (McGraw-Hill, 1961)
[3] MD Rashid.: „Modern power electronics", Proc. IEEE, 1964, 111, (5), pp. 1040-1048
[4] MD Singh Khanchan Dhani,: "Power electronics ", (Tata McGraw-Hill,1988)
[5] Switching theory and logic design: Hi-tech publishers, (K. Subba Rao)
[6] Original Equipment Manufacturer of DC-AC Rotary Converter, Technical Design and Operating Instructions.
[7] Naval Engineering Standards for designing electronic Equipment for installation onboard ships.
[8] Naval Engineering Standards for designing of Earthing for electronic equipment