COMPARISON OF TWO-LEVEL AND THREE-LEVEL NEUTRAL-POINT CLAMPED CONVERTER OF METRO TRAIN SYSTEM

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ABSTRACT

A reliable public transportation i.e. a world class Mass Rapid Transit System is an integral part of infrastructure development of India.

While evaluating different mass transit system, metro system is given preference as road based bus system cannot cater to passenger capacity as much as metro system. Metro system is operated in under-ground, elevated above street level therefore it is most suitable public transportation system in the cities. Metro train system also reduces road accidents and air pollution. Due to higher level of comfort, speed and efficiency, rail based system is found most favorable, in terms of saving time as compared to a road based system.

To maintain operation & punctuality of a metro system, its converter inverter system should be reliable and efficient. This report highlights the comparison of the two level converter and three level neutral point clamped converter for the application in Delhi Metro Trains.

Literature survey regarding two level converters and three level Neutral point clamped converters has been done.

Simulation has been done in MATLAB to compare the two level and three level converters. Comparison of the total harmonic distortion of the two level and three level neutral point clamped converters have been done through MATLAB Simulation.

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INTRODUCTION

1.1 General:

At present, the Delhi Metro network has total six (6) Operational Llines. Two more lines i.e Line 7 and Line 8 are under constructions. Line 1 to 4 is covered under Delhi metro project phase I and II. Line 5 and Line 6 is covered under Delhi metro project phase-II and Line 7 and Line 8 is covered under Delhi metro project phase-III.

Metro trains for Line 5 and line 6 are procured under Rolling Stock Contract RS3 (RS3 Project) and trains for Line 7 and 8 are procured under Rolling Stock Contract RS10 (RS10 Project).

In RS3 project as well as in RS10 project, Converter/ Inverter have been supplied by Mitsubishi Electric Corporation, Japan. In RS3 project, two level converters has been used whereas in RS10 project, three level neutral point clamped converter has been used.

This project highlights the performance comparison between two level converters and three level neutral point clamped converter used in Delhi Metro project.

1.2 Overview of traction system/propulsion system in metro system:

1.2.1 Traction system in metro system:

The function of the traction system is to transmit the electrical energy from the Catenaries to the vehicle. The consumers of the traction system are propulsion system and the electrical auxiliary system. 25 KV, 1 Phase, 50 HZ voltage is supplied to the train from the Catenary.

Block diagram of Traction System in RS3 Project

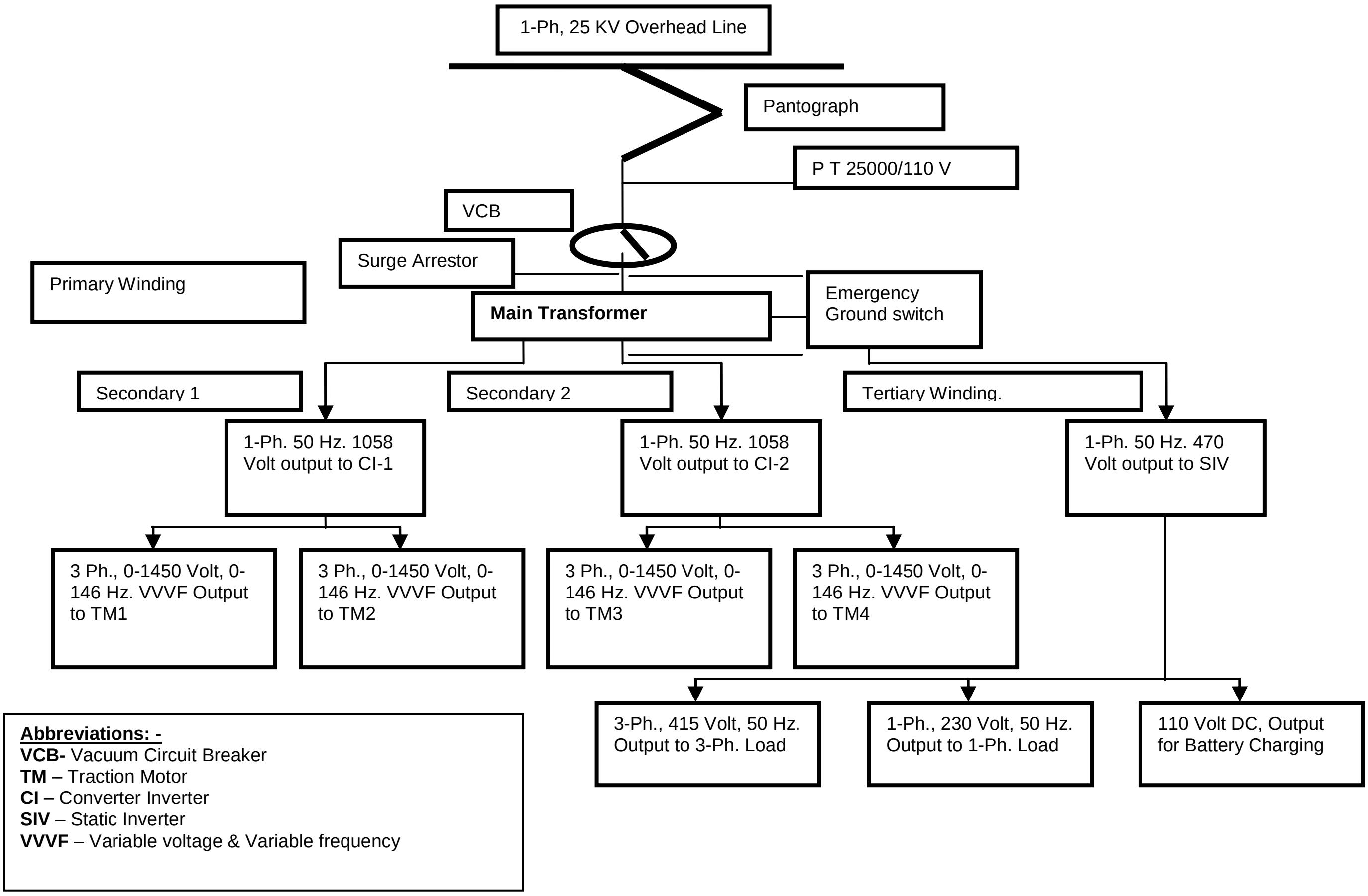


Fig.1.1: Block diagram of Traction system in RS3 Project

1.2.2 Propulsion system in metro system

Propulsion System is a system in which traction is required to move the train in controlled manner. The function of the propulsion System is to drive the Train by feeding three phase variable Voltage & variable Frequency (VVVF) to Traction Motor. VVVF is produced By Converter & Invertors (C/ I).

1.2.3 Converter- Inverter (CI) in Metro Trains

The CI box contains the high Voltage equipments required to convert the power coming from the main transformer into a power source suitable for operating of the traction motors.

Function of Converter/ Inverter (C/I):

- Produce Variable Voltage.
- Produce Variable frequency .

- Control the level of voltage & frequency.
- Convert the Dynamic kinetic energy to voltage and feed it to voltage system & catenary as desired.
- C/ I is controlled by IGBT (Integrated Gate Bipolar Transistor System).

1.2.3.1 Overview of CI of RS3 Project (2 level converter):

C/I box is installed in the underframe of Motor car of the Train. The function of C/I is to control Train acceleration and deceleration according to driving commands given by drivers in cab through Master controller and Mode selector by suitably converting the power drawn from the Main Transformer to operate the Traction Motors.

One Converter/ Inverter box houses two C/I set. Each C/I set feed power to two Traction Motors. Each Converter/Inverter set is controlled independently by one Gate control unit i.e. Micro Computer based system.

The CI box contains the high Voltage equipments required to convert the power coming from the main transformer into a power source suitable for operating of the traction motors.

There are two CI sets per CI Box. Each is fed independently by the secondary winding of the Main Transformer. The CI power equipments housed in a CI box is sub system of traction System and is required for variable voltage variable frequency (VVVF) controlled Propulsion System.The CI units consists of the IGBT modules (Insulated gate Bipolar transistor) also called IPMs (Intelligent Power Module) with control and self-protection functions incorporated.The IGBT modules used consist of High Power High Voltage semiconductor device called IGBT, Gate drive circuit and its own protection circuits against over current, short circuit, over temp and low power supply (Low control voltage) detection.

The converter unit carries out PWM control, making it possible to attain zero phase difference between the primary voltage and current of the main transformer. In other words, a unity power factor can be achieved. During normal powering operation, the converter unit converts 1058 V AC obtained in the Secondary winding of the main transformer to a constant DC voltage of 1900V. The multi-phase (Bridge connection Type) Converter used reduces the ripple contents in the rectified voltage to less than 5% of nominal voltage at DC stage.

Basic Diagram of Converter /Inverter Power circuit of RS3 Project

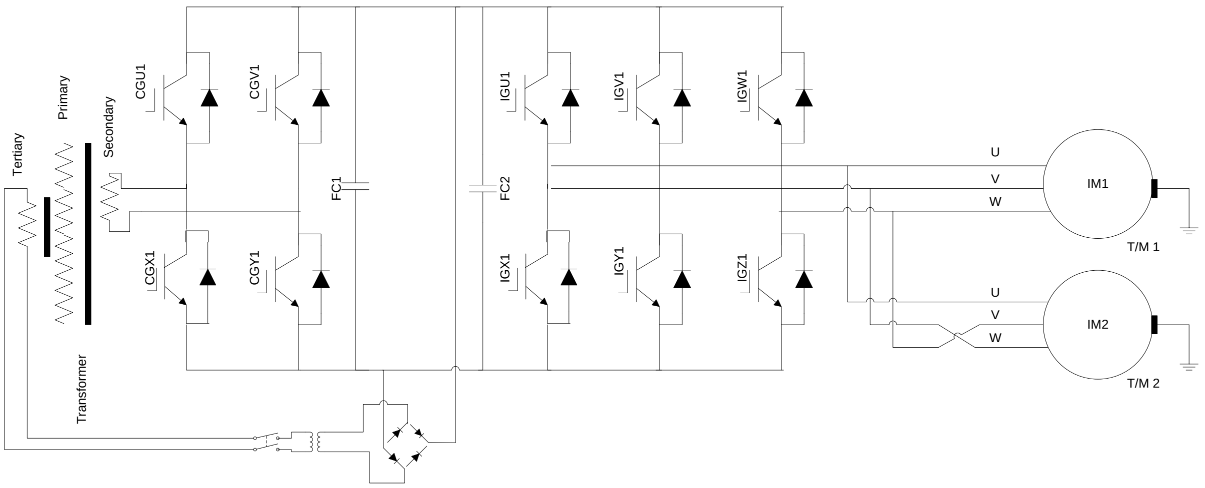


Fig.1.2: Basic Diagram of CI Power circuit of RS3 Project

- Input Voltage : 1058Vac at 25kVac (at secondary winding)
- DC link voltage : 1900Vdc
- Output circuit: 3phase, 0 to 1450Vac, 0Hz to 150Hz , 255kW induction motor driven in 2 parallel

The Inverter unit inverts the output of converter i.e. DC power supply at 1900 V DC into AC power supply at a desired output voltage and frequency. The Inverter unit controls the voltage applied to the traction motors to obtain the desired level of tractive effort and the frequency to change the traction motor speed. This control also called VVVF is achieved by controlling the on/off timings of the IGBTs through a microcomputer (gate control unit) in the Inverter control circuit.The Inverter unit on the motor side in the main conversion equipments converts 1900V DC to the three phase AC voltage which is necessary to drive the three phase induction motors. The Inverter unit consists of the same IGBT modules. This Inverter can carry out variable voltage variable frequency (VVVF) control to control the number of rotation of the Traction motor. i.e. the speed of the train, over a wide range.

It can switch powering/regenerative operation and forward/ reverse operation without switching the main circuit by slip frequency and output phase permutation controls, i.e. only by controlling gates signal.

During regenerative brake operation, the converter unit is also capable of inversely converting 1900 V DC to 1058 V AC, providing efficient powering and regenerative operations without switching the main circuit.

Gate control unit and gate interface of CI units is connected through the optical fibre cables. The optical fibre cable transmits the gate signal to drive the IGBT via gate interface. The optical fibre cables provide electrical isolation between IGBT and the gate control unit and are thus impervious to electrical interface.

AC contactors are installed onwards the secondary windings of the main transformer to prevent in rush current to the filter capacitor, when VCB is closed.

The charging transformer, charging AC contactor and charging diode are installed for initial charging of the filter capacitor.

In case of initial charging of the filter capacitor, the CHK is turned on firstly. The CHT steps up 470 AC obtained in the tertiary windings to 1350 V AC. The CHDs rectify AC voltage output of the CHT into DC voltage. When the Filter capacitor is charged upto 1500 V, CHK will turn OFF and subsequently K will turn ON.

To reduce the stray inductance between IGBT and filter capacitor, the filter capacitor is mounted very close to IGBT and the laminated bus bar is used for connection. So the IGBT can communicate without snubber circuit. The control target for voltage applied to the middle DC circuit is set at 1900 V DC. A large capacity Filter capacitor (FC) is provided to absorb ripple contained in the Converter output.

(A) Converter: control function and switching sequence

(i) **Control function:** The converter provides following two control functions

- Constant DC voltage control: controls the output voltage constant regardless of fluctuations in the input voltage and output current.

- Constant power factor (1.0) control: control the phases of the primary voltage and secondary current to be always the same during converter operation.

Details of the control system

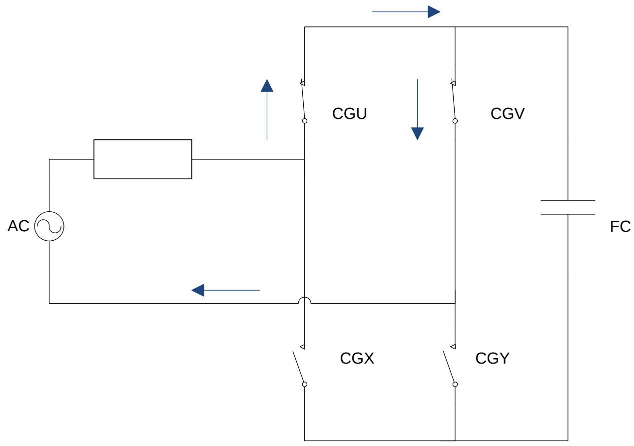
- Creating a unit sine wave: The primary voltage is a sine wave signal. This is passed through a frequency filter to eliminate harmonics frequency and the fundamental wave component is obtained. From this fundamental wave component signal, a sine wave signal with amplitude of 1.0 is obtained for use as unit sine wave signal.

- Constant DC voltage control: Unlike the control target value corresponding to constant DC output voltage of the converter, the actual output voltage from the converter contains the ripple of the output voltage. For this reason, an average output is fed back, and the difference is entered to the constant- voltage control system. This signal is used to determine the input current required maintaining the output voltage of the converter at a constant value.
- Constant power factor (1.0) control: The input current pattern is a DC level signal. This is multiplied by a unit sine wave signal to output a sine wave signal synchronized with the primary voltage signal. Using the sine wave signal Is*, the input current pattern, as a target value, the secondary current Is is fed back to detect the amplitude and phase difference between the two. This detected value is denoted to Is. The delta is multiplied by the gain. This signal is used to control the phase difference between the primary voltage and secondary current at zero i.e the signal maintains the power factor at 1.0

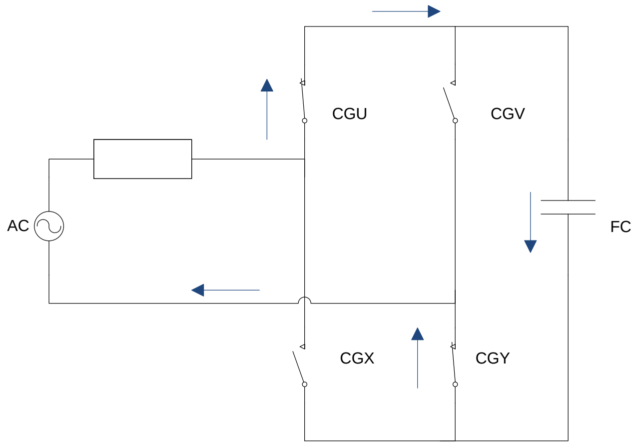
(ii) Switching Sequence of 2 level Converter:

The switching IGBT is controlled by PWM signal. The switching situation at the mode (1) to (4) (powering) are shown as below:

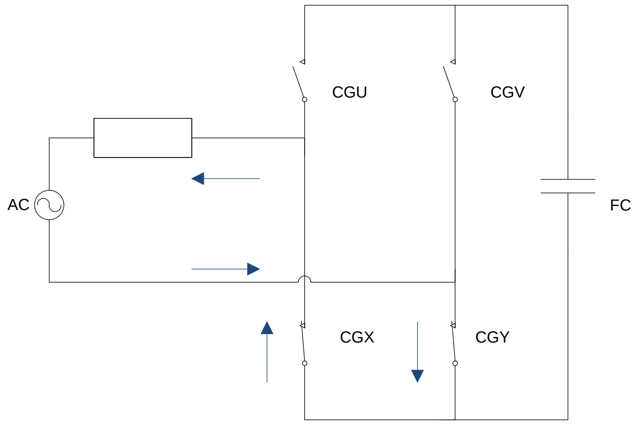
- At mode (1), CGU and CGV turn on. The reactor is short circuited and charges the electrical energy in itself.
- At mode (2), CGU and CGY turn on. The filter capacitor is charged by the voltage of DC link circuit.
- At mode (3), CGX and CGY turn on. The reactor is short circuited and charges the electric energy in itself as mode (1). But the current flow through the reactor is opposite.
- At mode (4), CGX and CGY turn on. The filter capacitor is charged by the voltage of DC link circuit as mode (2).



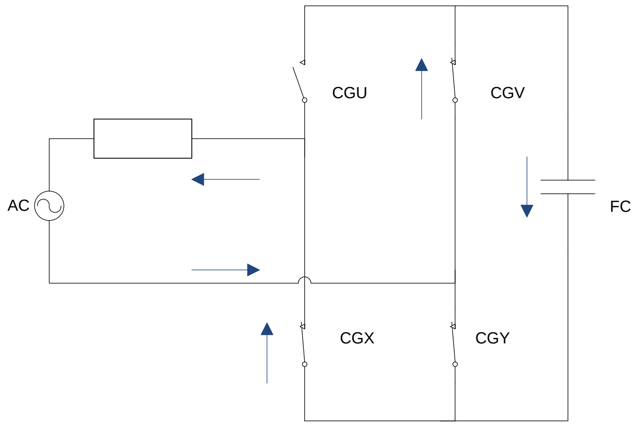
Mode 1



Mode 2



Mode 3



Mode 4

Fig.1.3: Switching sequence of two level converter

(B) Inverter operation

Vector control method for traction drive: Vector control is a high performance induction motor (IM) control technique. It gives the motor a fast dynamic response as well as good steady state performance. The torque can be instantly controlled. This means that the effects of load disturbance on speed are minimized, and slip slid of the wheels can be easily controlled and minimized. The flux and torque are controlled separately in vector control. This means that the maximum torque per current can be obtained under both transient and steady state conditions. Hence the efficiency is higher and the electric current capability of the drive is better utilized.

The basic principle of vector control is to transform the motor model equations frame of reference to a synchronous rotating d-q axis. These axes are 90 degrees apart in phase, and rotate at synchronous speed. The rotor flux is always kept on the d axis. This decouples the flux and torque, and allows the torque and flux to be separately controlled.

The method developed is classified as indirect rotor flux oriented vector control. The method developed uses feed-forward control of the motor stator voltages and feedback control of the stator current.

(i) Control Method

In the control approach developed the stator voltage commands are generated as a feedforward signal. Thease feedforward voltages in the d and q axis are defined as:

$$e^{ff}_{ds} = R_s^* \, i_{ds}^* - \omega_{inv} L_s^* \sigma \, i_{qs}^* \quad (1)$$

$$e^{ff}_{qs} = R_s^* \, i_{qs}^* - \omega_{inv} L_s^* \sigma \, i_{ds}^* \quad (2)$$

In these equation the currents and frequency are defined by assuming that the direct axis corresponds exactly to the angle of the rotor flux i.e. the q axis component of the rotor flux is zero at all times. This means that the following conditions apply:

$$i_{qs}^* = (T^* L_r^*)/(\Phi_r^* P M^*) \quad (3)$$

$$i_{ds}^* = \Phi_r^*/M^* \quad (4)$$

$$\omega_s = (R_r^* \, i_{qs}^*) / (L_r^* \, i_{ds}^*) \quad (5)$$

$$\omega_{inv} = \omega_s + \omega_r \quad (6)$$

Where:

e^{ff}_{ds} = feed forward voltage of the stator d axis

e^{ff}_{qs} = feed forward voltage of the stator d axis

R_s , R_r = Stator, Rotor Resistance

L_s , $^*L_r$ = Stator, Rotor Inductance

M = Mutual Inductance

P= Pole Pair Number

i_{ds}^*= d axis component of the stator current

i_{qs}^* = q axis component of the stator current

ω_{inv} = inverter output frequency

ω_s = controlled slip frequency

ω_r =rotor speed frequency

σ = leakage coefficient frequency = $1-M^2/L_sL_r$

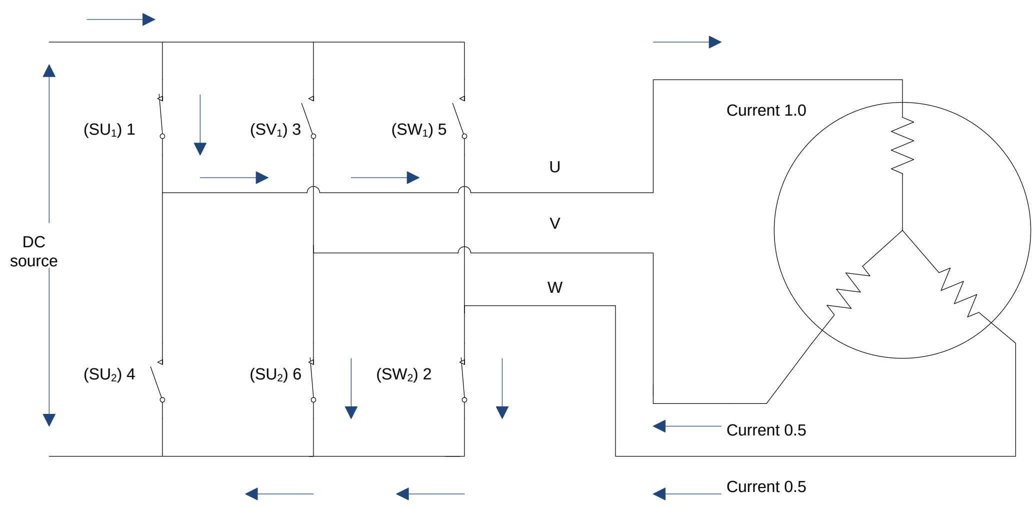
T*= motor torque command

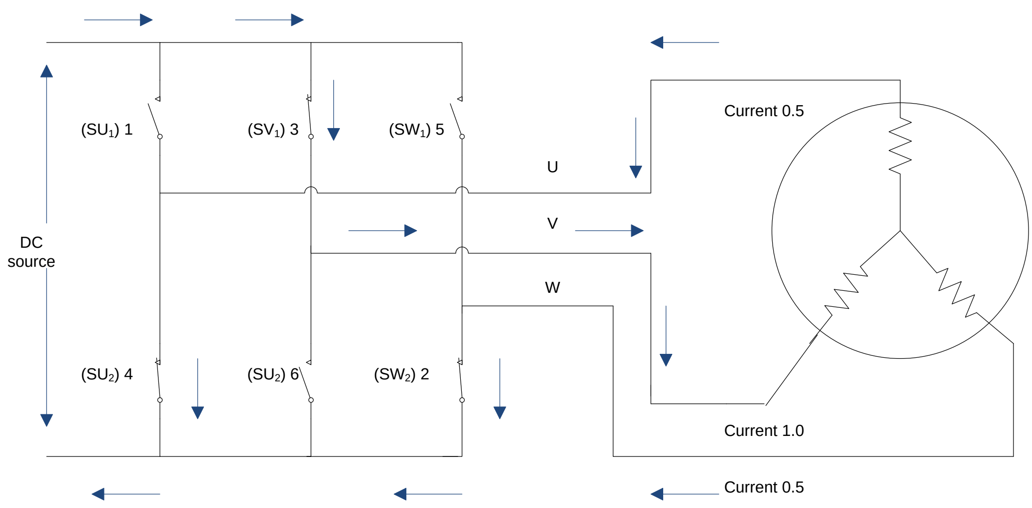
Φ_r = rotor flux amplitude

In combination with the feed forward voltage control, there is a PI current controller, which controls the d and q axis currents of the motor to equate to the command currents (Eq 3 & 4).

Therefore, this scheme uses a combination of feed forward voltage control and current control to generate the required currents in the motor, to maintain rotor field orientation (i.e. the q axis component of rotor flux equal to zero), and permitting instantaneous control to the field torque.

(ii)Switching Sequence Outline of Inverter (2 level)





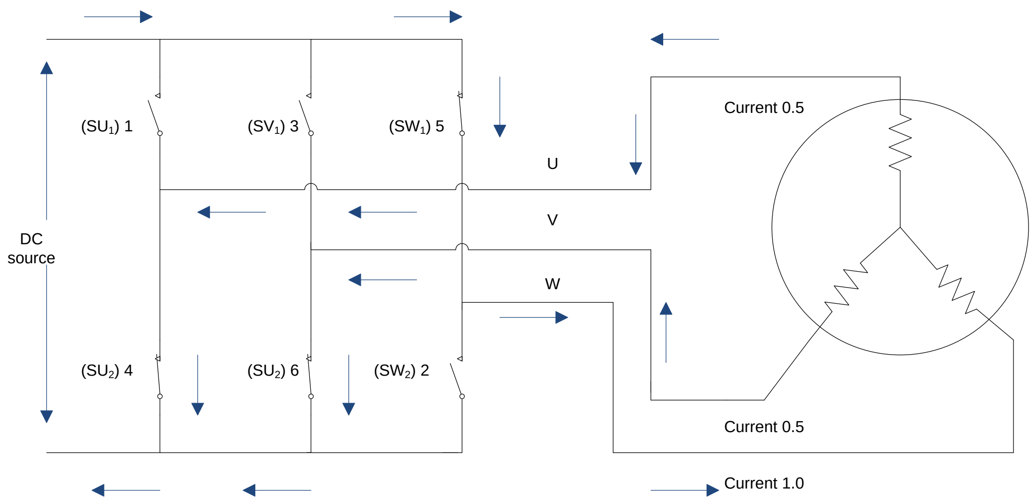


Fig.1.4: Switching sequence of two level inverter

1.2.3.2 Overview of CI of RS10 Project (3 level converter):

The traction converter/inverter system makes DC power from AC power coming from the secondary winding of MTr by the single phase converter and makes three-phase AC power to drive four traction motors by the three-phase inverter. In the regenerative braking mode, the regenerative power from the traction motor is changed to DC power by the three-phase inverter and the DC power is changed to AC power by the single-phase converter and then the regenerative power shall be turned back to the catenary line through the MTr.

Input Voltage : 951Vac at 25kVac (at secondary winding)

DC link voltage : 1800Vdc

Output circuit: 3phase, 1400Vac, 0Hz to 150Hz , 255kW induction motor driven in 4 parallel

The main transformer is equally divided into four parts on the secondary side. Each winding is connected with a PWM converter incorporating power semiconductors. A reactor function is added to the secondary windings of the main transformer. The converter on the line side of the converter/ inverter box converts 951Vac at 25kV obtained in the Secondary windings of the main transformer to a constant DC voltage of 1800V. This converter consists of the IGBT modules with control and self-protection function. The converter carries out PWM control, making it possible to make the phase difference between the primary voltage and Current of the main transformer a zero. In other words, a power factor of 1.0 can be obtained. During regenerative brake operation, the converter is also capable of inversely converting 1800V dc to 951V ac, providing efficient powering and regenerative operation without switching the main circuit. The converter on the motor side (inverter) in the main conversion equipment converts 1800V dc to the three-phase AC voltage which is necessary to drive the three-phase induction motor. The inverter consists of the IGBT module and this inverter can carry out variable voltage variable frequency control to control the number of rotation of the traction motor, i.e., the speed of the train, over a wide range. It can switch the main circuit of the main conversion equipment incorporates two converter circuits and 1 inverter circuit which consist of a single-phase PWM converter circuit, a DC filter capacitor, and a VVVF inverter circuit.

The AC contactor (K), charging AC contactor (AK) and charging resistor (CHRe) are installed on the one secondary windings of the main transformer. The only AC contactor (K) is installed on the other secondary windings of the main transformer.

The control target for voltage applied to the middle DC circuit is set at 1800V dc. A large capacity filter capacitor (FC) is provided to absorb ripple contained in the converter output. When the DC link voltage reaches to the set value (over voltage protection), the over voltage transistor is turned on continuously and discharging the filter capacitor to zero volt through over voltage resistors. The upper and lower half voltage of DC circuit are detected by the DCPT and DC link voltage is controlled to keep the balance of the upper voltage and lower voltage using these DCPT's. DCPT11/ DCPT12 is connected between the positive terminal and neutral point of DC circuit and DCPT12/ DCPT22 is connected between the negative terminal and neutral point of DC circuit for over voltage protection.

The middle DC circuit is charged using pre charging circuit which includes charging AC contactor (AK) and charging resistor (CHRe). Firstly, charging AC contactor is closed to charge the filter capacitor through charging resistor and then AC contactor K is closed.

Basic Diagram of Converter /Inverter Power circuit of RS10 Project

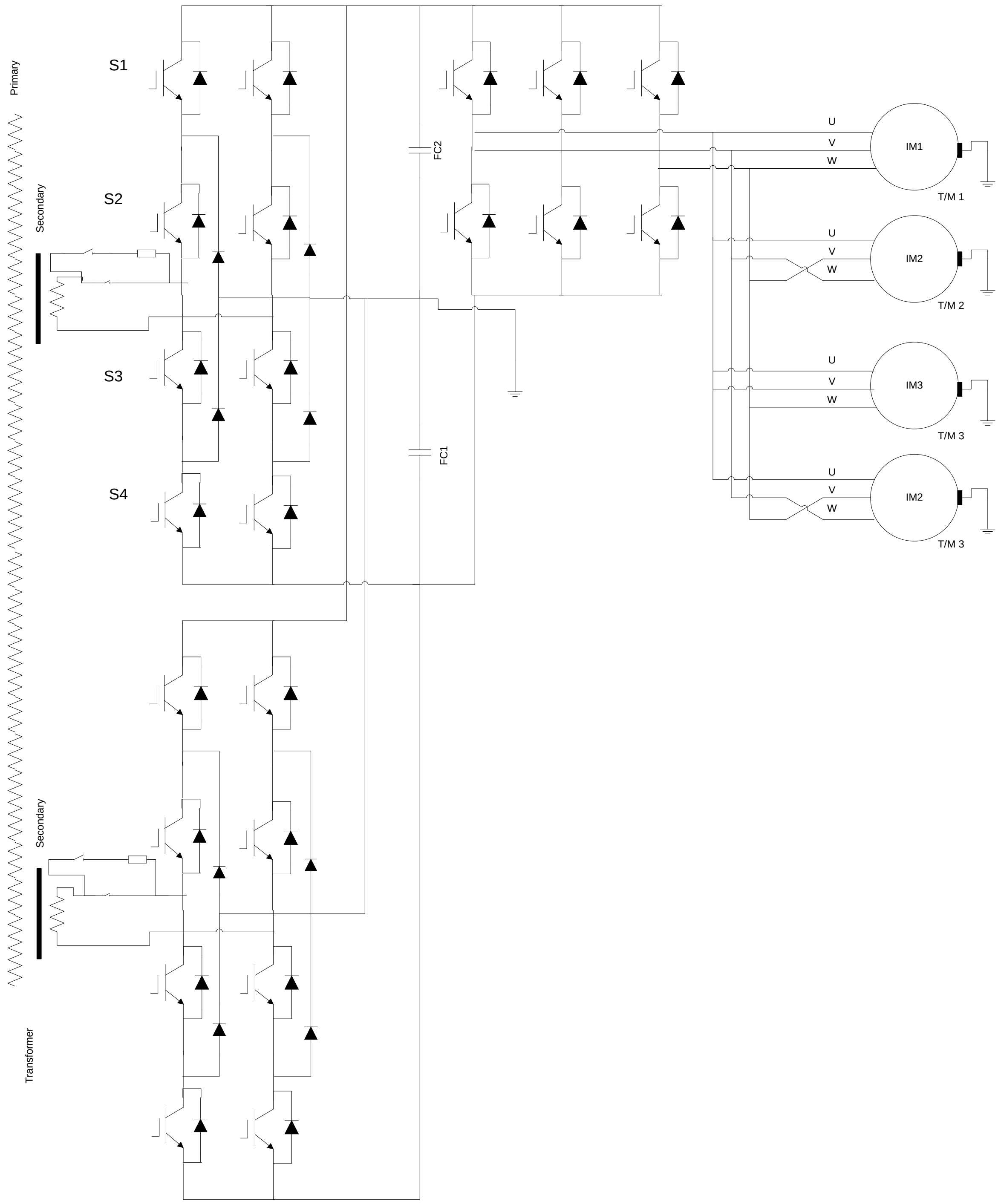


Fig.1.5: Basic Diagram of CI Power circuit of RS10 Project

Switching State of Diode Clamped

S. N.	Switching State	Output Voltage
1	S1 = ON, S2 = ON	+VDC
2	S2 = ON, S3 = ON	**0**
3	S3 = ON, S4 = ON	+VDC

CHAPTER 2

LITERATURE SURVEY

Near sinusoidal voltage can be generated by multilevel converters with only fundamental switching. Multilevel converters are also suitable for large volt-ampere drives. With a control strategy which operates the switches at fundamental frequency, it is concluded that the converters have low THD and high frequency power factor. Multilevel converters are suitable for high voltage motor drives. Since switches of multi level converter systems can be switched at minimum frequency, these multilevel converter systems have higher efficiency. For multilevel inverters which are used as a rectifier in case of regeneration, Power factor is close to unity. Charge unbalance problem is not faced when converter is in rectification mode or inversion mode [1].

In the area of high power medium control, the multilevel inverter has emerged as an important alternative. The cascaded multilevel inverter was introduced in 1975. However the commercial products which utilises this topology were available by mid 1990. The most important topologies such as neutral point clamped diode inverter, capacitor clamped and cascaded H- Bridge multilevel converter [2].

The main drawbacks for the three level neutral point clamped diode converter is, the lack of modularity and unequal loss distribution. Voltage balancing problems due to increasing voltage blocking stress of the clamping diodes are structural problem with NPC diode converters with more than three levels. The additional expenses of flying capacitors at low carrier frequencies and high number of cells are the main disadvantage of the flying capacitor topology. The main disadvantage for the CHB is the separate DC sources. The CHB is particularly attractive for reactive power compensation since no complicated transformer is required and also for very high power applications because the series connections make a natural increase of power level of converter. The FC is mainly used in high bandwidth applications. Finally the neutral point clamped diode finds substantial markets that require a high converter efficiency and low switching frequency at a lower cost as compared to other two topologies [3].

In 1981, proposal of a new neutral point clamped PWM Inverter composed of main switching devices was made. It was presented that this inverter output contains less harmonic than that of conventional type. Two converters were compared and experimentally and analytically. A new PWM technique which is suitable for ac drive system was applied to the inverter. It was concluded that the NPC PWM inverter adopting new PWM techniques shows better and excellent drive system efficiency along with motor efficiency and this is appropriate for a wide range variable speed drive system. The authors carried out experiments, driving 3 phase, 200 V, 2.2 kW, 60Hz squirrel cage induction motor with NPC PWM inverter. To eliminate fifth and seventh harmonics, the PWM technique adopted. When PWM technique is applied to the NP PWM inverter, to eliminate the fifth and seventh harmonics, it was observed that the eleventh and thirteenth harmonic is far less than as compared to conventional Inverter. Experimental results showed that approx. 93% inverter system efficiency and 97% ac input power factor at the rated motor output. A conventional inverter is composed of six switching devices, whereas NPC PWM is composed of twelve switching devices. The NPC type is better than conventional converter [4].

In recent years, three phase four wires PWM converters have been widely used in distributed power generation, active power filters, DVR and phase PWM rectifier. Three level converters have following advantage as compared to traditional 2 level converters:

- Each power semiconductors withstand half dc link voltage, which decrease dc link voltage and reduce the electromagnetic interference.
- With same switching frequency, harmonic content of output voltage and current is reduced.
- Switching losses of semiconductor power devices is reduced

Due to above reasons, 3 level converters have became more popular than conventional type converters. However the one problem in NPC inverter is neutral point voltage variation resulting from neutral point current which leads to increase of voltage stree on the switching devices.

Following method is used to avoid the NPC inverter neutral point voltage variation

- Two separate DC power supplies can be used resulting in increase of cost.
- Extra converters can be used to control neutral point voltage, resulting in extra cost
- Control logarithm can be adopted to achieve neutral point voltage balance.

The negative level and positive level are called non-zero level. When output voltage is zero level, neutral point current is zero. Zero level has no effect on neutral point voltage. If zero level is replaced by non- zero level in the switching cycle, neutral point current will change and neutral point voltage can be regulated. Therefore, in order to reduces dc capacitance, neutral point control strategy is to be done. By experiment it is concluded that control strategy has a good effect on the neutral point voltage balance [5].

Multilevel converters are being used widely in high power applications such as motor drives, wind generation, utility applications. Multilevel converters can provide more than two voltage levels. The generated voltage and current waveforms have low total harmonic distortion. These topologies are based on power devices connecting in series. Therefore, high voltage can be handled on both the ac and dc side of converters. The NPC is most widely used topology. This topology has main difficulty how to keep the neutral point voltage at one half of the dc link. Under certain operating conditions, a low frequency voltage oscillation appears in the NP. Therefore, the capacitors and the converters must be oversized to ensure that they can stand the high voltage occurred due to oscillation. When a common mode voltage is inducted into the modulation signal, it causes imbalance in the dc link discharge. However, these type of compensators don't take into account the instantaneous value of output currents or other parameters related to the operating point. However an optimal controller which consists in adjusting a proper offset to the modulation signals and produces optimal balancing results for all operating condition of converters [6].

A noval modulation strategy for NPC converter is required to overcome the one of the main problem of the NPC converter which is low frequency voltage oscillation that appears in the neutral point under some operating conditions. The Fast-processing modulation strategy for the NPC converter with total elimination of low-frequency voltage oscillations in the neutral point describes that this strategy can completely eliminate this removal for the all operating points for all kinds of load, even non linear unbalanced loads. This technique can also attain the maximum amplitudes that are achievable under linear modulation. The drawback of this strategy is that the switching frequencies of the devices are one third higher than standard SPWM for any modulation index under linear operation mode [7].

The multilevel power converters main advantage is less drive stress, less converter loss and less voltage harmonic distortion as compared to two level converters. The NPC three level inverters require 50% higher rating than a comparable two level inverter for a fixed frequency operation without optimization of capacitor rating. The reliability of electrolyte capacitors is smaller than that of film capacitors. It is the major driving reason to reduce the value of capacitance and to use film capacitor as dc link capacitor. By using a film capacitor instead of electrolyte, compact design and low cost of an AC drive can be achieved. These drives are known as small DC link capacitor based drives. Neutral-point current modelling and control for neutral-point clamped three-level converter drive with small DC-link capacitors shows that the NP current is proportional to the output power of the converter. In this modelling, a PI controller is used to control the midpoint voltage of the three levels. The simple implementation of this controller and modulation strategy requires minimal computation [8].

The implementation of space vector modulation is complex for multilevel inverters. A two level inverter based Simple Vector PWM algorithm for a multilevel inverter is based on standard two level inverters and its implementation. This algorithm is explained for a 3 level inverter and it is also generalised for any number of levels [9].

Multilevel topologies have ability to synthesize voltage with lower harmonic content than two level converters. It has also ability of operation at higher dc voltages using series connected semiconductor switches. The phase disposition method gives lowest harmonic distortion. In contrast, SVM identify each switching state as a point in complex. Then a reference phasor rotating in the plane at the fundamental frequency is sampled within each switching period and then nearest three inverter switches states are selected with duty cycle which is calculated to achieve same volt second average as the sampled phasor reference. In two level inverters, carrier and space vector modulation methods create exactly same phase leg switching sequence when appropriate zero sequence offset is added to the reference waveforms for carrier modulation. Discontinuous modulation can be applied to multilevel inverters by using zero sequence offset voltage which is derived from two level inverter space vector controls.

CHAPTER 3

MATLAB SIMULATION OF TWO LEVEL CONVERTER AND THREE LEVEL (NPC) CONVERTER

3.1 General

MATLAB simulation has been done and presented in chapter of two level converters and three level NPC converter which is being used in DMRC in RS3 project and RS10 project respectively.

(i) The Input voltage, DC link voltage and output parameters of two level converter being used in RS3 project is as below:

- Input Voltage : 1058Vac at 25kVac (at secondary winding)
- DC link voltage : 1900Vdc
- Output circuit : 3phase, 0 to 1450Vac, 0Hz to 150Hz , 255kW induction motor driven in 2 parallel

(ii) The Input voltage, DC link voltage and output parameters of three level converter being used in RS10 project is as below:

- Input Voltage : 951Vac at 25kVac (at secondary winding)
- DC link voltage : 1800Vdc
- Output circuit : 3phase, 1400Vac, 0Hz to 150Hz , 255kW induction motor driven in 4 parallel

In this thesis, MATLAB simulation of 2 level converter has been done by supplying 1058 Vac line input to converter and 1900V dc is found. Similarly MATLAB simulation of three level NPC converter is also done by supplying 951 Vac line input to three level NPC converter and 1800 Vdc observed. In these simulation 200HP squirrel cage Induction Motor (field oriented control Induction motor drive) for simulation purpose of 2 level converter and three level NPC converter.

The THD analysis is done for 2 level converter and three level NPC converter and it is found that THD of 2 level converter is more as compared to 3 level NPC converter.

3.2 MATLAB simulation of two level converter:

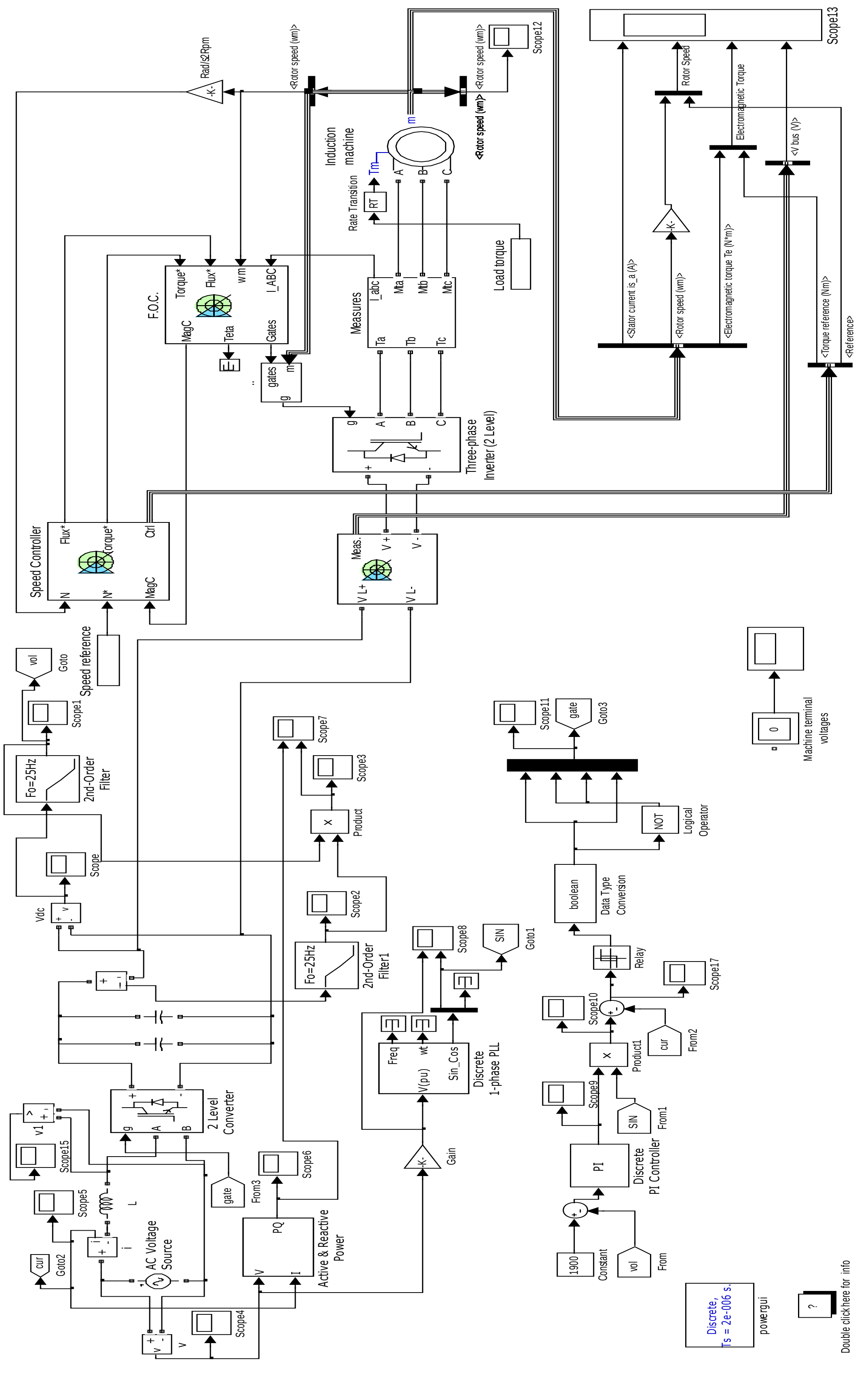


Fig 3.1: Simulink model of the 2 level converter

3.2.1 Waveforms of simulation results of 2 level converter

(i) Waveform of Line voltage supplied to 2 level converter is observed as below:

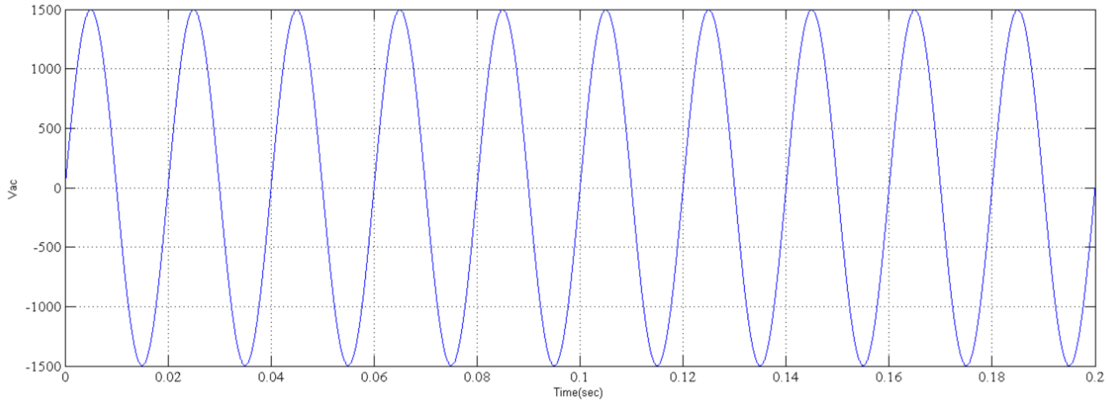


Fig 3.2: voltage waveform of source supply input to converter

(ii) Waveform of Line current supplied to 2 level converter is observed as below:

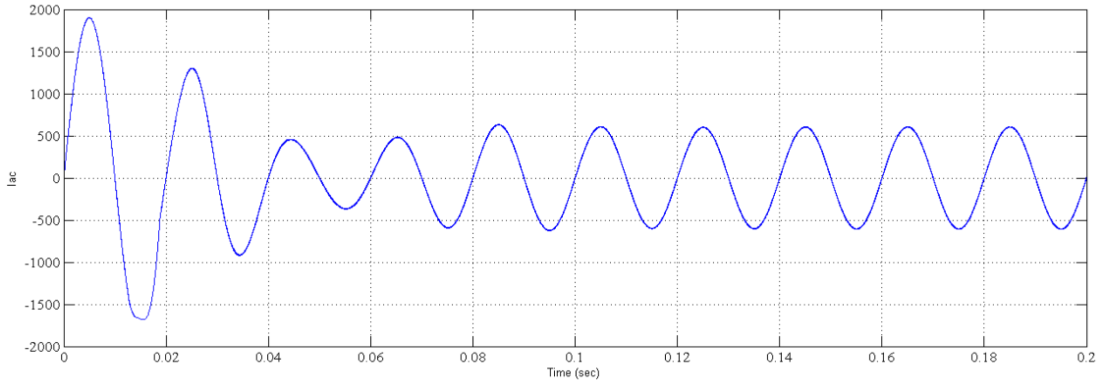


Fig 3.3: current waveform of input to converter

(iii) Waveform of 2 level ac voltage of converter is observed as below:

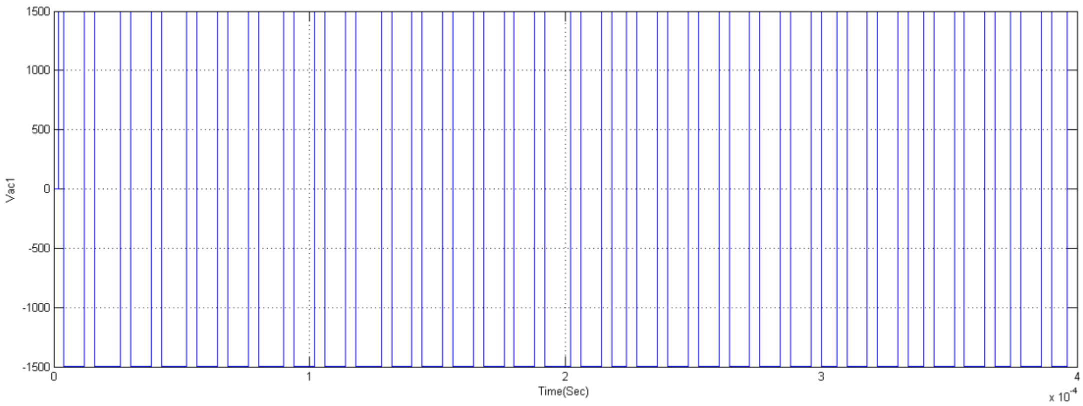


Fig 3.4: 2- level voltage waveform input to 2 level converter

(iv) Result of 1900 dc link voltage is achieved and its waveform is as below:

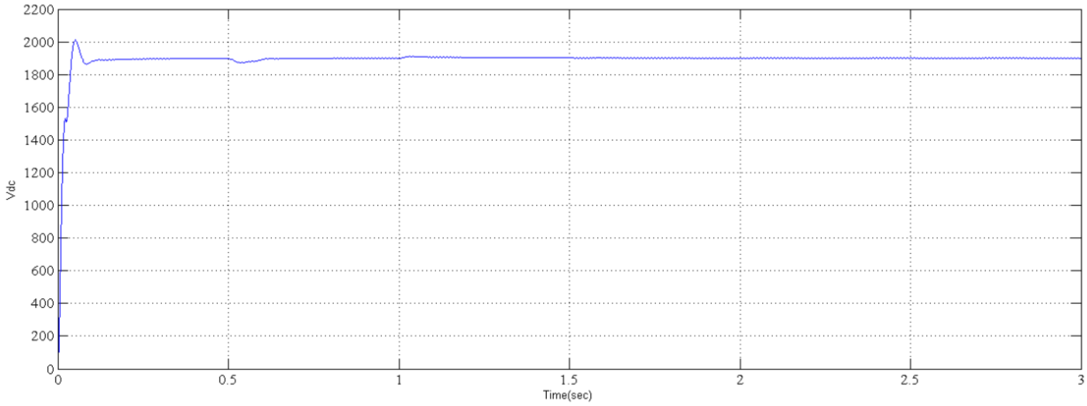


Fig 3.5: dc link voltage waveform

(v) Waveform of dc link current is observed as below:

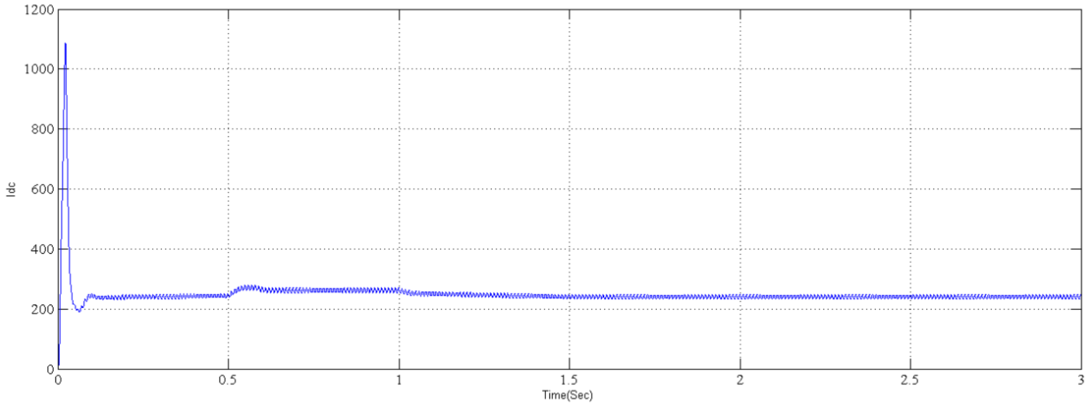


Fig 3.6: dc link current waveform

(vi) Waveform of dc link current is observed as below:

In waveform result, it can be seen that speed is precisely following the acceleration ramp. The speed set point is 500 rpm at time t=0 sec.

Nominal load torque is applied to the motor at 0.5 sec and the speed set point is changed to 0 rpm at t = 1 sec.Then The speed decreases to 0 rpm. The mechanical load passes from 792 Nm to -792 Nm at t = 1.5 sec.

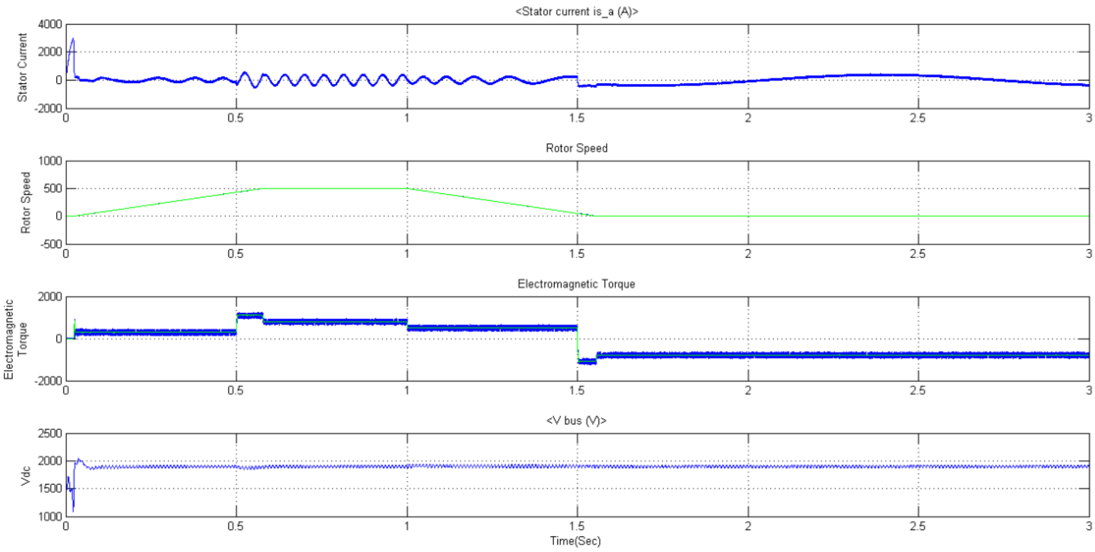


Fig 3.7: waveform of simulink results of field oriented control Induction Motor by using 2 level converter

3.2.2 THD of two level converter is observed as below. At start time 0.2 sec, and after considering no. of 3 no. of cycles, the THD of 2 level converter is 89.07%

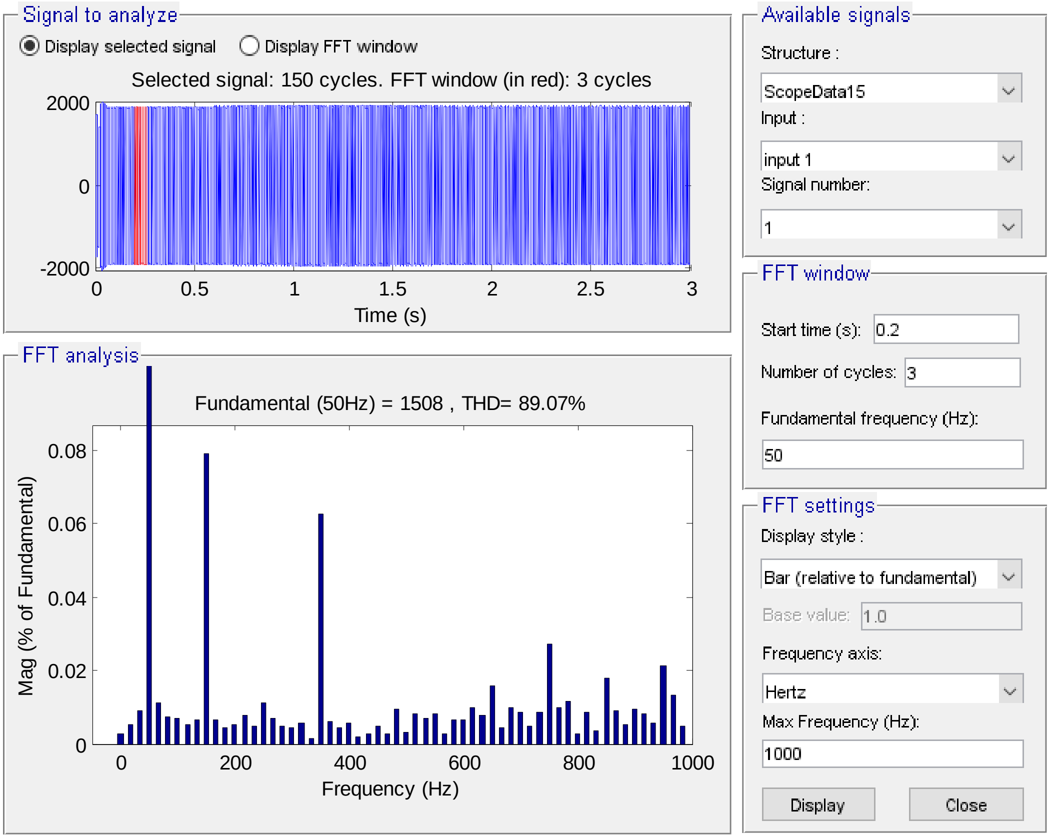


Fig 3.8: Line voltage THD of 2 level converter

3.3 MATLAB simulation of three level NPC converter:

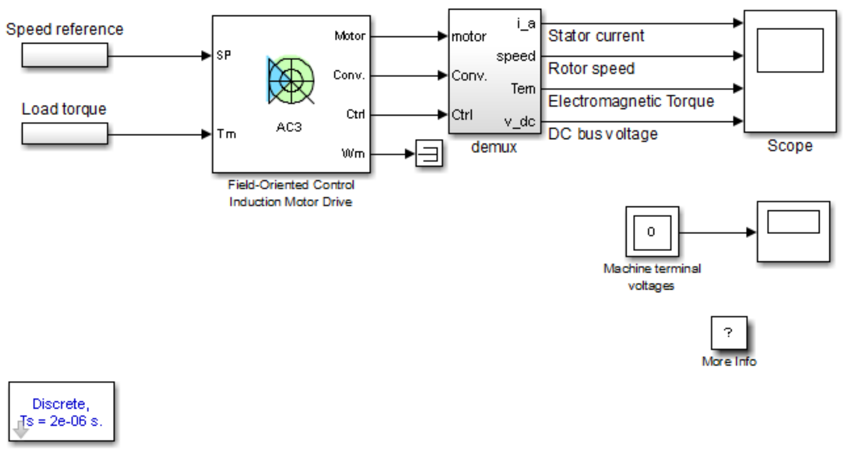


Fig 3.9: Simulink model of field oriented control Induction Motor using 3 level converter

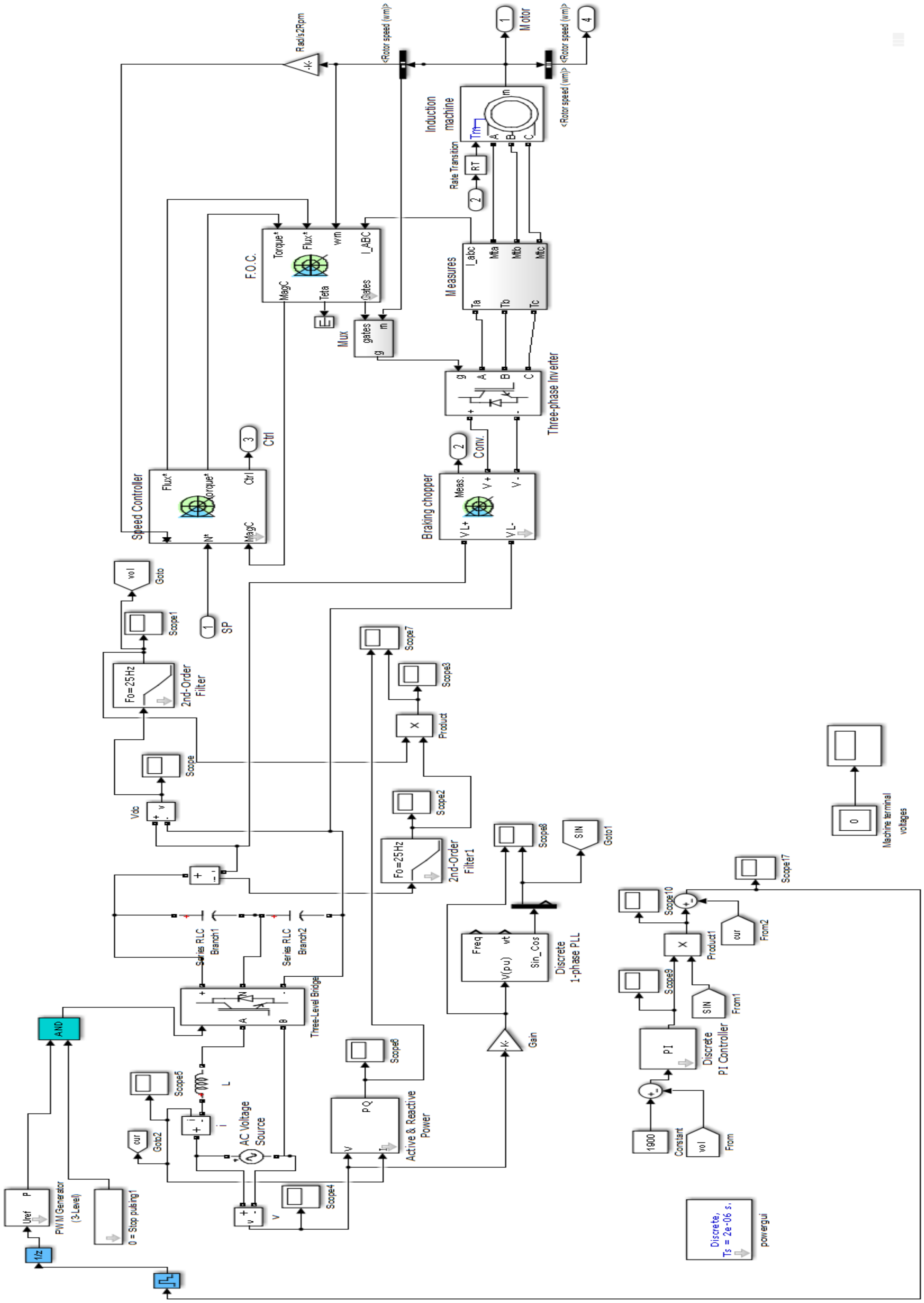


Fig 3.10: Simulink model of the 3 level converter

3.3.1 **Waveforms of simulation results of three level NPC converter**

(i) Waveform of Line voltage supplied to 3 level converter is observed as below:

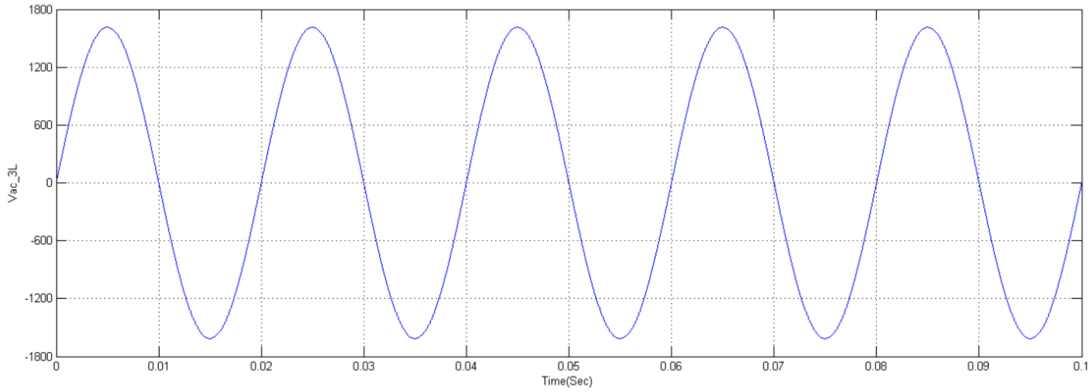


Fig 3.11: Voltage waveform of source supply input to converter

(ii) Waveform of Line voltage supplied to 3 level converter is observed as below:

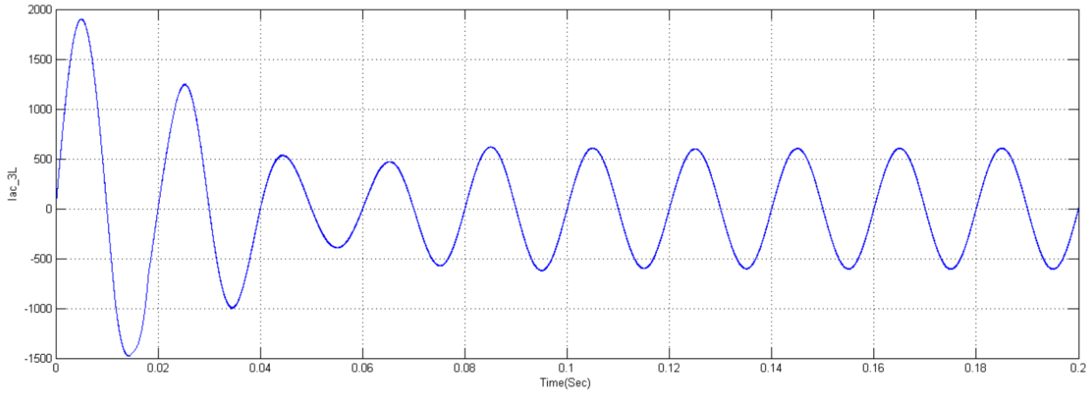


Fig 3.12: current waveform of input to converter

(iii) Waveform of 3 level ac voltage of converter is observed as below:

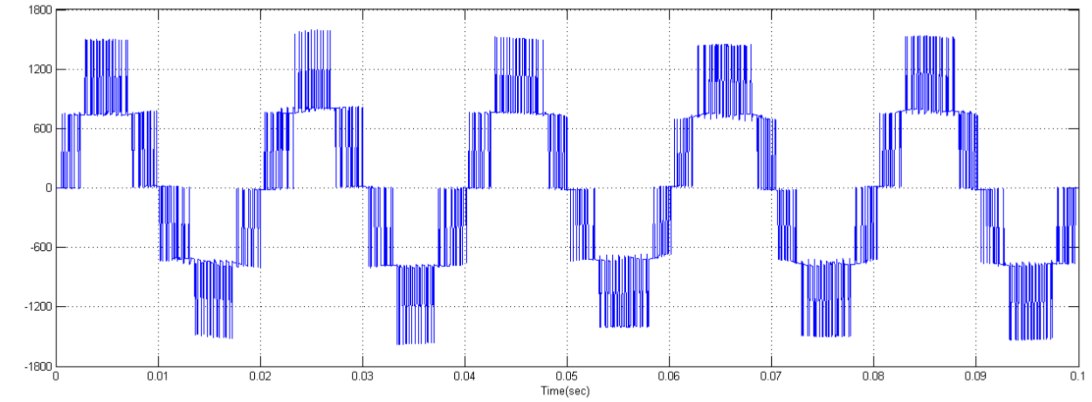


Fig 3.13: 3- level voltage waveform input to 3- level NPC converter

(iv) Waveform of 3 level dc link of converter is observed as below:

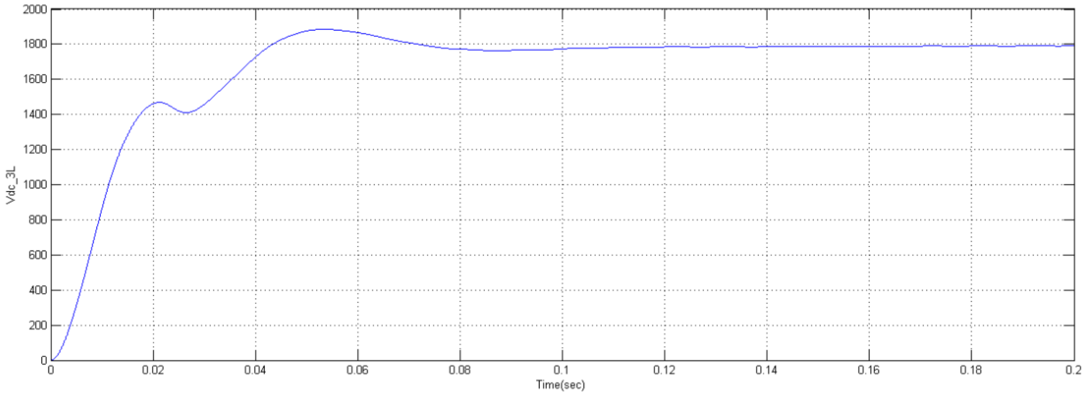


Fig 3.14: dc link voltage waveform

3.3.2 Line voltage THD for 3 level NPC converter

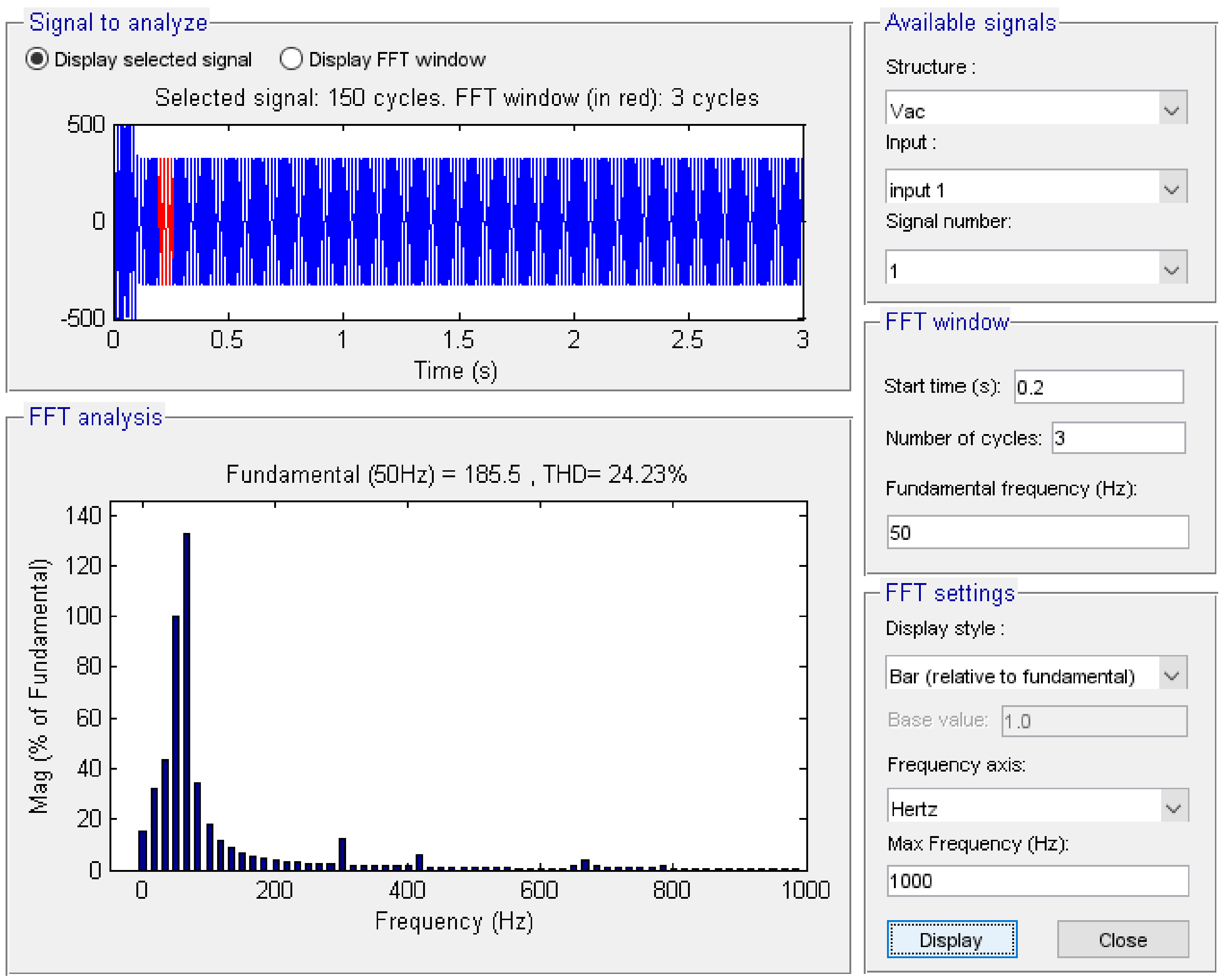


Fig 3.15: Line voltage THD for 3 level NPC converter

CHAPTER 4

CONCLUSION

Since efficiency is important power goal in Power Electronics, therefore initiatives to be taken to improve performance and reduce energy consumption.

Chapter 1 explains than in Delhi metro system has adopted 3 level NPC converter in Converter Inverter of traction system in current project which was 2 level converter in earlier project

In chapter 2, literature survey has been done and it is observed that with respect to efficiency, losses, switching frequency, junction temperature and for an entire range of speed and torque of an electric vehicle three-level NPC converter is a better candidate compared to two level.

For two level and three-level NPC converter, the THD of line-to-line voltage has been compared in chapter 3 through simulink and it is found that THD of three-level NPC converter is lesser than 2 level converter .

This thesis, explain about 2 level converter and 3 level NPC converter used in Delhi metro system and its validation has been done by MATLAB / SIMULINK and by literature study.

It can be concluded that the three-level NPC inverter is much better with varied advantages for metro traction system compared to 2 level converter.

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