Impedance Network Based Advanced Boost Converter with Energy Storage Capability for Light Electric Vehicle Applications

by

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Table of Contents

List of Figures

Abstract

With the world moving towards more sustainable sources of energy, the automobile industry too has shifted focus from more fossil fuels towards more sustainable electric vehicles. One of the most propitious and practical sustainable solutions, electrified vehicles are cleaner and greener. As the electric vehicles continue to gain popularity in automobile markets, more efficient ways of power flow and energy conversion are needed. For this purpose, Power Electronics plays an increasingly important role in EV/ Hybrid applications.

The Electric Motor, along with its Electric Power converter and controller, makes an electric drive for an EV application. One of the biggest challenges of these systems for vehicle applications is to provide highly efficient and high reliable performance at an affordable cost.

A high-performance Z-source inverter is a great alternative for this application instead of traditional inverter architecture. A Z-source inverter can provide simultaneous buck-boost capabilities, which is of incredible importance in Electric Vehicle applications.

In this research, a new structure for the Quasi Z-source inverter is proposed, that introduces an energy storage device in the form of a super capacitor. The main aim of introducing the super capacitor is to improve the overall durability of the electric circuit. The energy stored in the supercapacitor can also be used to maintain the battery state of charge and can also be delivered to the motor to increase its performance. To validate the feasibility of the proposed structure an electric drive train model containing proposed structure along with a Brushless DC motor is built using PSIM software and simulation are run for each charging and discharging of the

supercapacitor and motor speed and voltage across the super capacitor is analyzed for each operation mode.

Chapter 1: Introduction

1.1 Background

Emissions from fossil fuel burning automobiles are clogging air and are major contributing factor to global warming. Stimulated by the supply concerns and over-exploitation of these resources, finding an alternate source for the automotive industry is of prime interest today, Although, there are several potential candidates for vehicle propulsion, the most readily available and accessible is electrical power. The introduction of electric motors for propulsion has required a new architecture of drivetrain in the vehicle, one which comprises of electric motor, power electronics converter, and energy storage devices like high voltage battery. Power Electronics play an increasingly important role in EV applications; it provides a highly efficient and compact solution for power conversion. The EVs make use of AC Motors due to their high efficiency and smoother control for the propulsion of the vehicles. However, the power supply in an electric vehicle is a high voltage DC battery. To efficiently utilize the energy from the batteries, an inverter is used, which converts the DC voltage to motor required 3 Phase Alternating current. [1-2]

A traditional Voltage Source Inverter is primarily used for this operation. However, an impedance source (Z-source) inverter is a great alternative, introducing a Z-source inverter also illuminates a front boosting capability and ensures the safety of the inverter circuit.

A Z-source inverter, also called an impedance-source inverter, was first proposed by Professor Fangzheng Peng in 2003[3]. Later in the year 2008, Professor Peng Fangzheng introduced a

Quasi-Z source converter, which was based on the Z-source inverter topology. A Quasi Z-source inverter (QZSI) can boost the bus voltage and recycle the regenerative energy. The buck/boost and regeneration functions of Quasi Z-source Inverter is achieved by controlling the duty ratio of the switches in the three-phase legs. No addition of dead time is needed as the bridge legs are used to boost the DC voltage, making it more reliable than the traditional inverters. The reliability and efficiency provided by these inverters can be very well be used to improve the performance of the motor drives.

1.2 Approach

In this thesis, the fundamental impedance network structure has been investigated first, to study their characteristics and provide a control design of the system that aims to increase performance of the motor drive system further. [4] As the first step to this research, construction of the permanent magnet synchronous motors (PMSM) is studied in detail, along with control strategies primarily focusing on field-oriented control. Based on the study, a PSIM simulation model is developed using the field-oriented control strategy with position sensors. The model was simulated and verified using a traditional bi-directional DC-DC inverter first. However, apart from a two-directional approach, the EV requirements also demand a buck-boost function simultaneously. For this reason, an impedance-based Z-source inverter is selected. A study on Z-source inverter is conducted, and their boost capabilities were studied. Based on the study, the inverter model is built and verified using PSIM.

A final PSIM model of Z-source inverter with the energy storage is built and verified using a charge and discharge current and observing the motor performance during the charge and discharge cycle of the supercapacitor.

Chapter 2: Motors

2.1 Introduction

An Electric Motor is an electro-mechanical energy conversion machine that can process the electrical energy and converts it into rotational mechanical energy to and delivers power for load operation. The same can also act as a generator and be used for mechanical to electrical conversions. The advancement in the development and manufacturing of electric motors has made them more efficient and robust. The electrical motors have seen an increase in vehicle applications, where previously they were used for small purposes such as windshield wiper & windowpane motors, both bigger and powerful motors are now capable of vehicle propulsion.

Permanent Magnet Synchronous Motor (PMSM) sees a rise in usage for electric vehicle applications because of their high efficiency, provide high torque to current ratio, high power density, compact structure, and rapid dynamic response. [1] However, the focus of this research is on brushless DC motors (BLDC), due to their cost effectiveness and low voltage applications.

The Electric Vehicles use of the DC and Induction motors. Light Electric Vehicles use brushless permanent magnet motors (BLDC) over induction motors as they are highly efficient and provide high torque and power density. However, compared to a BLDC, a Permanent Magnet Synchronous Motor has smoother control and negligible torque ripples. Thus, for an Electric Application, PMSM Motor is preferred over BLDC because of its sinusoidal back emf, which provides smoother control and results in a smooth and comfortable driving experience. [5]

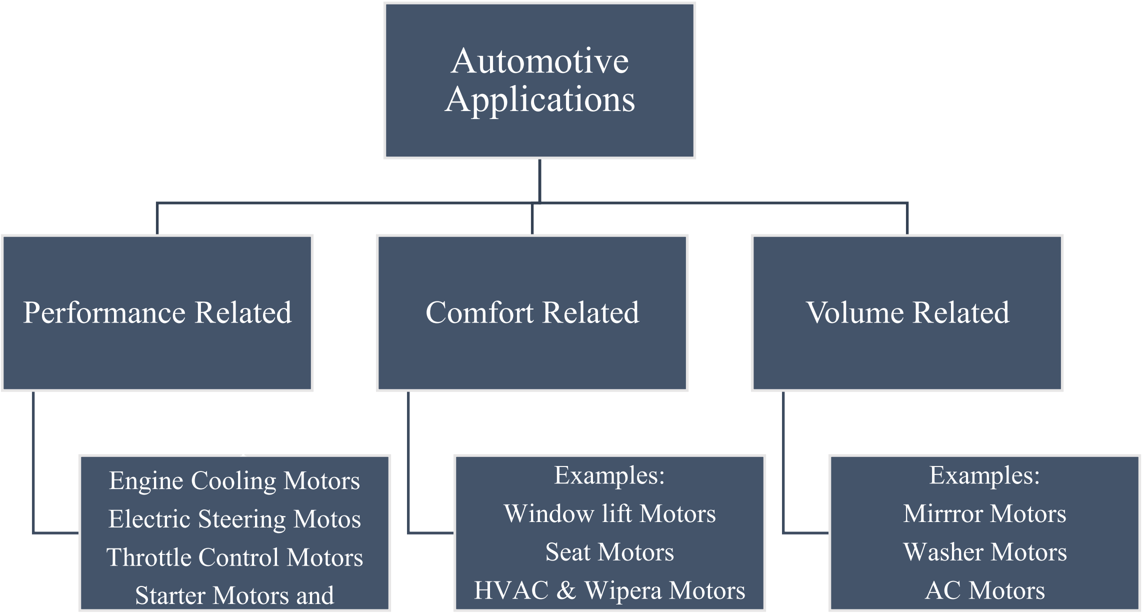


Fig. 1 Motor applications in a vehicle

2.2 Permanent Magnet Synchronous Motor

2.2.1 Construction

PMSM is seen as a cross between an induction and BLDC Motors. The permanent magnet rotor and windings on the stator share similarity with brushless DC motor. The main difference between synchronous and a PMSM motor is in the construction of the rotor; the rotor in PMSM is made up of permanent magnets instead of windings that are present in the synchronous motors. The field excitation is provided by these magnets, while the stator windings are excited by electrical power.

The permanent motors of the rotor can be mounted on the surface of the rotor (Surface Mounted PMSMs) or can be embedded inside the rotor (Buried or Interior PMSMs); however, the Surface Mounted PMSMs are not suitable for high-speed applications and do not possess reluctance torque. [6]

2.2.2 Working Principle

Permanent magnets on the rotor create a constant magnetic field. The PMSM working principle is based on this based on this continuous magnetic field and its interaction with the rotating magnetic field of the stator. The concept of the rotating magnetic field of the stator is the same as that of a 3-phase induction motor. The rotating torque is generated by the interaction of the magnetic field created by the permanent magnets in rotor with the rotating magnetic field produced by alternating current in the stator windings. [7]

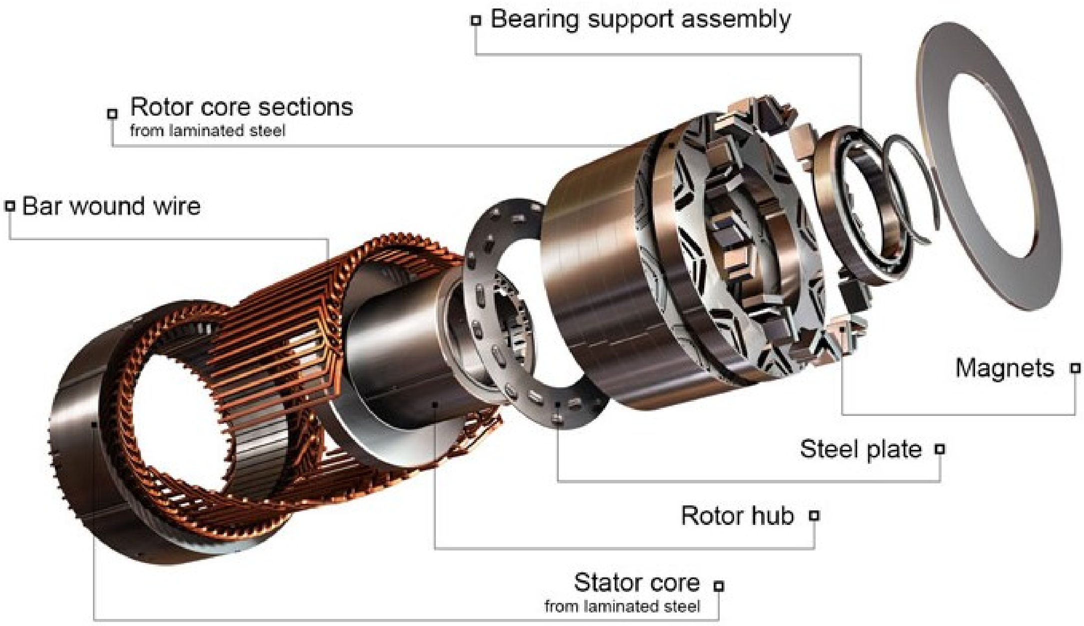


Fig. 2 PMSM construction [6]

The reactance torque is maximum when the rotor magnetic fields is perpendicular to the rotating stator field, to generate the torque this relationship should be maintained. A PMSM cannot start itself when connected directly to a 3-phase AC supply, at a synchronous speed the rotor poles interlock with the rotating magnetic field of the stator of the stator field. [6] As a result, no torque is generated from the motor.

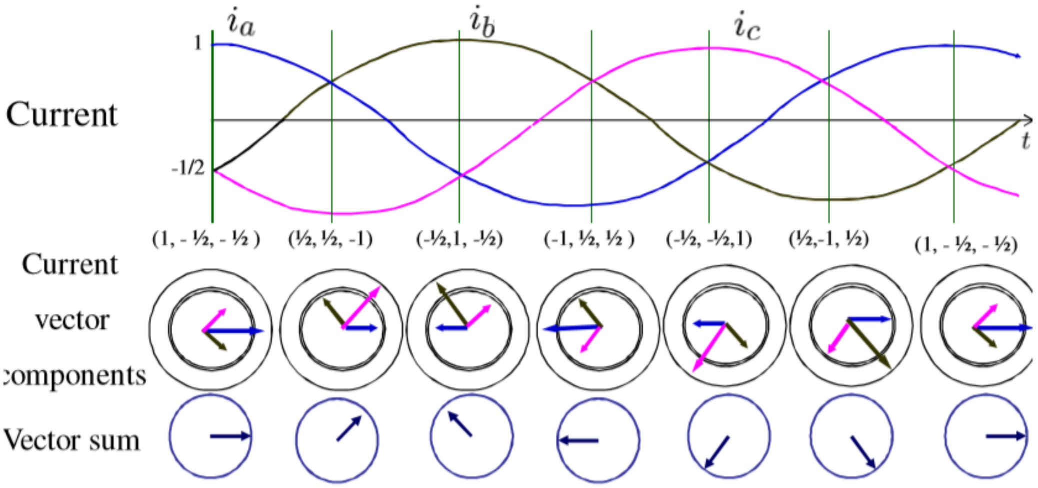


Fig. 3 Current vector rotation [8]

2.3 Brushless DC Motors (BLDC Motors)

2.3.1 Structure of BLDC Motors

Brushless DC motors are synchronous motors which have a permanent magnet rotor, their use varies widely from traction motors applications to servos motors. The concentrated windings in the BLDC motors help in increasing the torque density and makes them more efficient [9]. Current control strategy is often employed to the BLDC motor, with the assumption that torque is proportional to the current, however this relationship is far more linear and leads to big torque ripples which can be seen in the simulation results. The performance and speed torque characteristics of a BLDC motor are like that of a DC motor. The main difference between the structures of BLDC and DC motor is that the BLDC motors use electronic switches to reverse the polarity, while there are physical mechanical brushes and commutators to perform this function in DC motors. This makes BLCD cost effective and provides an ease in usage.

2.3.2 Types of BLDC Motors

The permanent magnet BLDC Motors are characterized based on the location of the permanent motor in the rotor and the shape of back-EMF produced. [9]

Based on the location of permanent magnets –

1. Surface Mounted Motors

As the name suggests, these motors have the permanent magnet located on the surface of the rotor. Since, the magnets are on the surface these types of motors have very small inductance variation they are relatively easy to build, from design perspective the skewed poles can be easily magnetized and can reduce cogging torque. [9]

2. Interior Mounted/Embedded Motors

The permanent magnets in this type of motor configurations are embedded in the rotor, these types of motors are favored for high speed operations, however they have high inductance variance as the air gap between the rotor varies with respect to rotation. [9]

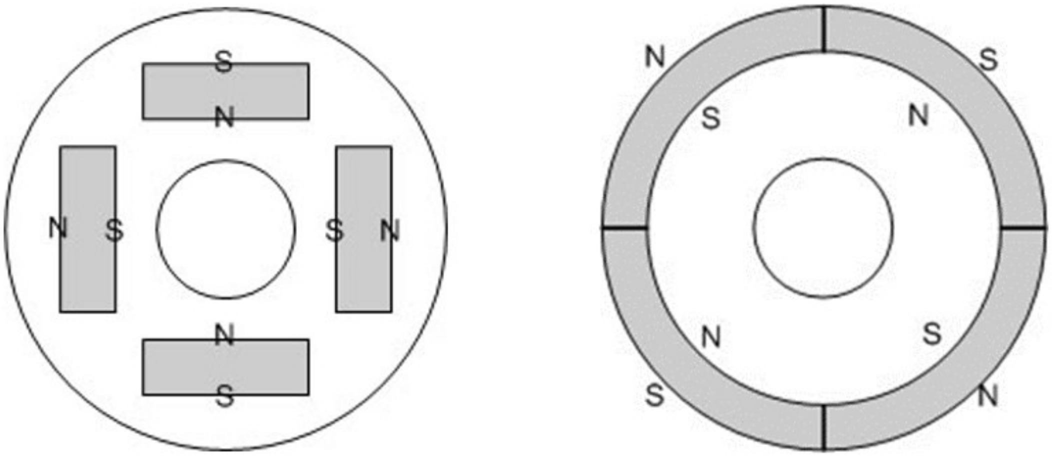


Fig. 4 Types of motor [9]; (a) Surface mounted (left); (b) Embedded motor (right)

Based on the type of Back-EMF

1. Trapezoidal Shape Back -EMF Type

These types of motors generate constant torque by utilizing the trapezoidal back-EMF along with square wave currents.

Characteristics of these motors are. – [9]

- Rectangular current waveform
- Simpler control
- Concentrated Stator Windings
- Rectangular distribution of magnet flux in the air
- Commutation torque ripple

The excited current takes form of quasi – square waveform with 60° intervals of zero excitation per cycle. This system allows some important system simplifications compared to sinusoidal back-EMF machine. The resolution requirements for the rotor position sensor are lower since only 6 commutation instants are necessary. [9]

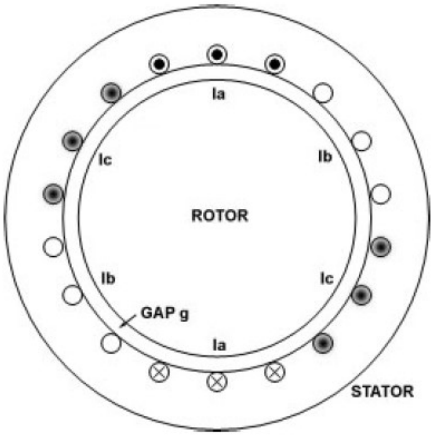


Fig. 5 Trapezoidal back-EMF BLDC structure [9]

2. Sinusoidal Shape back-EMF Motor

The back – EMF generated by each phase windings during rotation of the magnet is a sinusoidal wave function of the rotor angle. The basic operation of these motors is like that of AC Synchronous motor. The motors which produce a sinusoidal back – EMF are generally considered to be PMSM motors instead of BLDC. Sinusoidal shape back-EMF Motor show following characteristics [9]

- Sinusoidal Waveforms
- No commutation torque ripples
- Sinusoidal magnet flux distribution

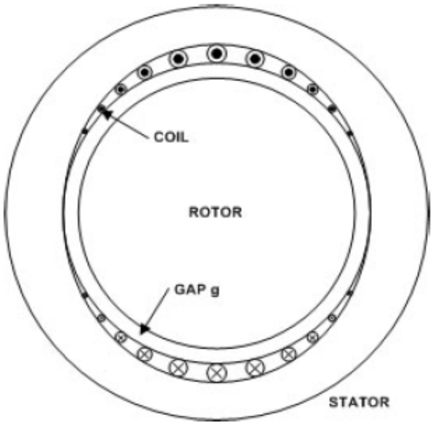


Fig. 6 Sinusoidal back-EMF BLDC structure [9]

2.3.3 Advantages and Disadvantage of BLDC Motors [9]

BLDC Motors have many advantages over their counter parts such as:

1. Compactness – They can achieve very high flux densities with the use of rare – earth material as magnets.

2. High Efficiency – BLDC motors offer highest efficiency among that of any other motors, as excitation of magnets does not consume much power and absence of mechanical brushes and commutators reduce any frictional losses.
3. Good thermal control – Lack of current circulation in the rotor results in negligible temperature rise in the motor.
4. Low maintenance, noise and increased reliability due to lack of mechanical components.
5. Ease of control – BLDC Motors can be easily controlled since the controlling variables are usually constant and easily accessible.

Disadvantages of BLDC Motors

1. Cost - Use of rare earth materials in building of these motors causes a rise in the initial cost of these machines.
2. Limited Constant Power range – BLDC motors have difficult field weakening operation due to permanent magnet usage.
3. High Speed Capability – These motors are not capable of performing at high speeds due to their assembly architecture.
4. Inverter Failures – BLDC Motors presents major risk of short circuiting due to presence of permanent magnets. Furthermore, a very large current in the windings and large torque can lead to blockage of the rotor.

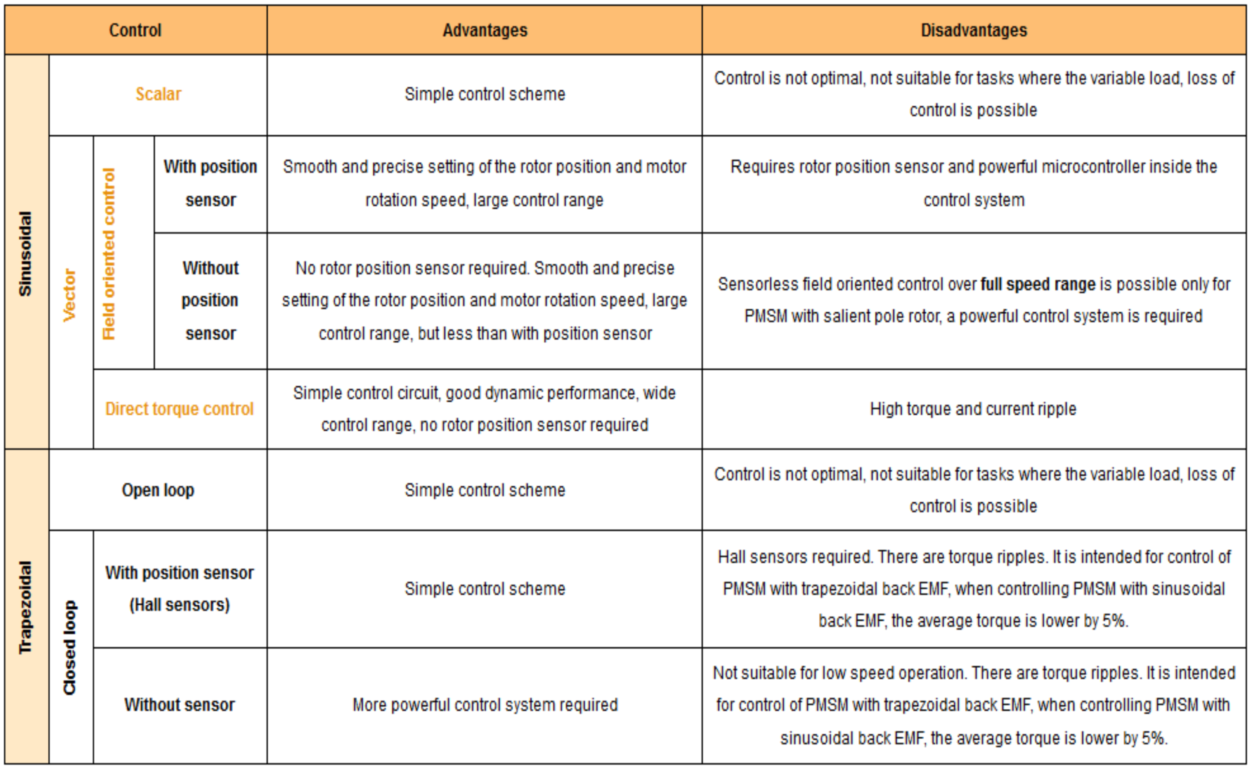
Chapter 3: Control Strategies for Motors

3.1 Introduction

The overall efficiency of the electric drive train is heavily dependent on the performance of the Permanent Magnet Synchronous Motor. Therefore, it is imperative that the motor is operated within the parameters that maximize its efficiency and performance.

The control strategies for the motors vary greatly depending upon the complexity and control level required. Major Control Strategies utilized for the control of PMSM are listed below in Table 1.

Table. 1 Major PMSM control strategies.[6]



Control				Advantages	Disadvantages
Sinusoidal	Scalar			Simple control scheme	Control is not optimal, not suitable for tasks where the variable load, loss of control is possible
	Vector	Field oriented control	With position sensor	Smooth and precise setting of the rotor position and motor rotation speed, large control range	Requires rotor position sensor and powerful microcontroller inside the control system
			Without position sensor	No rotor position sensor required. Smooth and precise setting of the rotor position and motor rotation speed, large control range, but less than with position sensor	Sensorless field oriented control over **full speed range** is possible only for PMSM with salient pole rotor, a powerful control system is required
		Direct torque control		Simple control circuit, good dynamic performance, wide control range, no rotor position sensor required	High torque and current ripple
Trapezoidal	Open loop			Simple control scheme	Control is not optimal, not suitable for tasks where the variable load, loss of control is possible
	Closed loop	With position sensor (Hall sensors)		Simple control scheme	Hall sensors required. There are torque ripples. It is intended for control of PMSM with trapezoidal back EMF, when controlling PMSM with sinusoidal back EMF, the average torque is lower by 5%.
		Without sensor		More powerful control system required	Not suitable for low speed operation. There are torque ripples. It is intended for control of PMSM with trapezoidal back EMF, when controlling PMSM with sinusoidal back EMF, the average torque is lower by 5%.

3.2 Field Oriented Control Strategy

Field Oriented Control strategy works on the basic idea of decomposing the stator current vector into a magnetic field-generating part and a torque generating part, both of which can be controlled separately. The structure of the motor controller (vector control controller), then becomes almost the same as a separately excited DC motor, which simplifies the overall control of PMSM.

The reactance torque of PMSM is generated by an interaction of two magnetic fields, represented by the magnetic flux/stator current and the constant magnetic flux of the rotor permanent magnets. These can be imagined as two bar magnets trying to repel each other. The repelling forces are maximum when the two are perpendicular to each other.

The stator current must be controlled in such a way that the stator current vector must always be perpendicular to the rotor magnet current vector for maximum torque production. This reactance torque is proportional to the ‘q-axis current’ As the rotor spins, the stator current must always be updated to maintain this relationship.

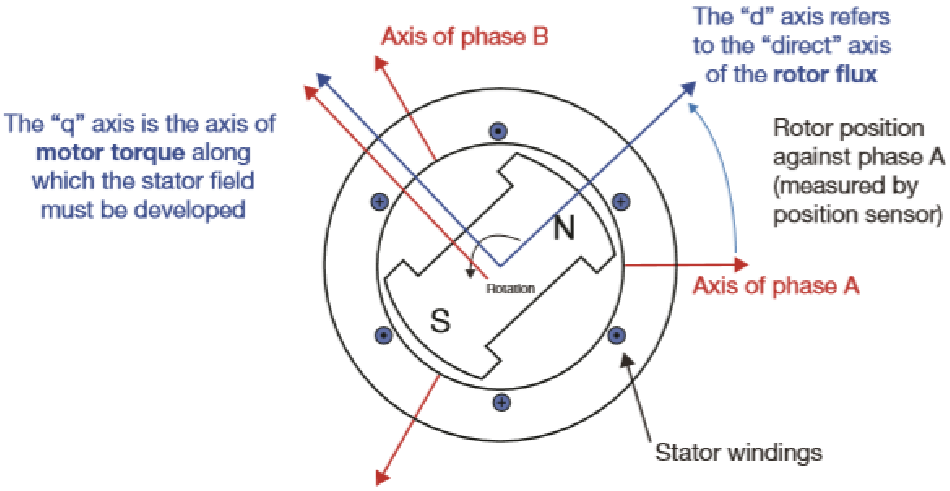


Fig. 7 Field-oriented control vector methodology [10]

3.2.1 Controlling Stator Current Vector

Controlling a DC Motor is more straightforward than a PMSM due to their steady-state conditions, and mechanical commuter controlling the current phase.

To control a PMSM motor using Field Oriented Control Strategy, it is necessary to know the rotor position, in advance. This is done using a position sensor. The rotor position aligned with phase A current is set to zero. The phase A current is already aligned with the direct axis ('d-axis'), which is the flux producing axis.

Steps for Vector Control

1. Measure input 3-phase motor currents.
2. Use Clarke Transformation to convert these 3-phase currents into 2-phase (**α-β**) stationary phase quantities.
3. Find Rotor Position Angle using the position sensor.
4. Use Park Transformation to convert **α-β** stationary axis currents into a rotating stator current **(d-q)** system.
5. Control the stator currents, (i_{sq} and i_{sd}) for the required torque values.
6. Output Stator voltage space-vector is transformed back into an (**α-β**) co-ordinate system using the inverse Park transformation.

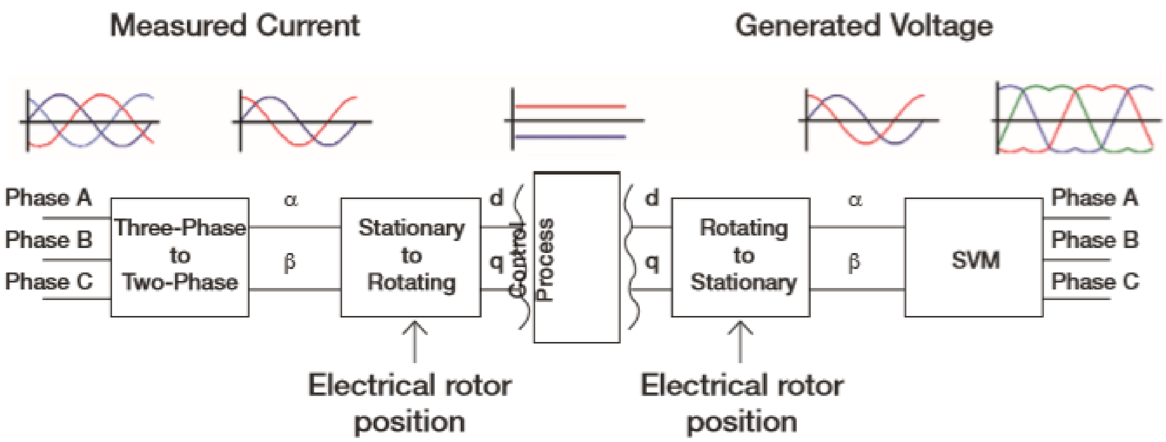


Fig. 8 Field-oriented control working principle

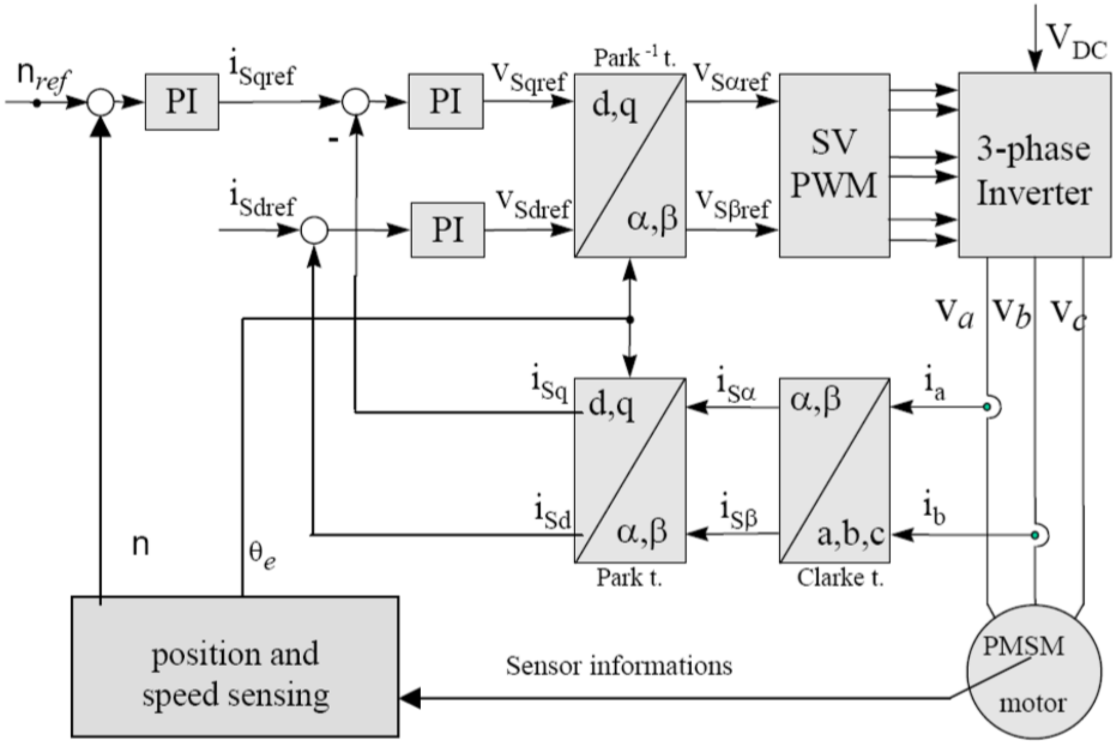


Fig. 9 Field-oriented control structure

3.2.2 Clarke Transformation

Clarke transformation is used to project the 3 phase current vectors (a,b, and c) onto a stationary 2 phase reference frame, namely α and β. The basis for this transformation is the assumption that the axis of α is the same as that of phase current.

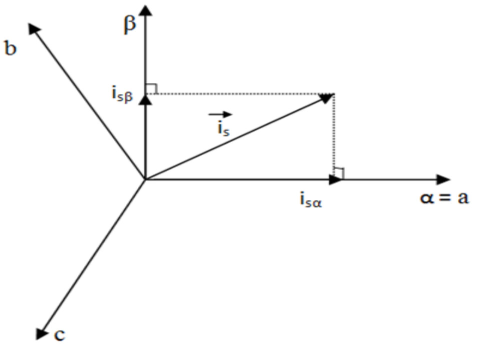


Fig. 10 Clarke transformation representation [11]

The phase equations used in this transformation can be represented by:

$$I_{s\alpha} = i_a$$

&

$$I_{s\beta} = \frac{1}{\sqrt{3}}\, ia + \frac{1}{\sqrt{3}} ib$$

3.2.3 Park Transformation

Park Transformation is used to transform the stationary phase vectors in the α and β to a rotating d-q frame. The following figure shows the Park Transformation.

The d-q projections can be represented by the following equations:

$$isd = is\alpha \cos\theta + is\beta \sin\theta$$

$$isq0 = -is\alpha \sin\theta + is\beta \cos\theta$$

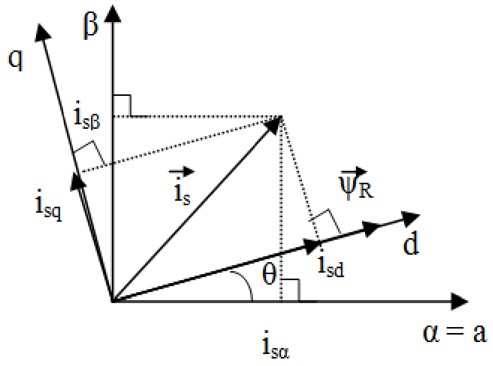


Fig. 11 Park transformation [11]

where θ is the rotor flux angle.

Advantage of Field Oriented Control Strategy [12]

1. Ability to control the stator flux and torque components
2. Increased reliability and efficiency of the system
3. Improved accuracy in transient and steady-state control.

Chapter 4: Inverter

4.1 Introduction

An Inverter is an electrical machine that converts Direct Current into Alternating Current at any given voltage and frequency. [9]

Electrical motors used to convert electrical energy into mechanical energy and primarily DC motors, however, they are unreliable and less efficient than AC Motors; thus AC motors have seen an increase in usage in applications for Electric Vehicles since the batteries provide a steady-state direct current, and the conversion of energy and power form high voltage DC voltage batteries to low voltage AC motors is accomplished with the help of an inverter.

Typically, inverters are of 2 types

1. Voltage source Inverter (VSI)
2. Current Source Inverter (CSI)

Inverters commonly use the following approaches to convert direct current to alternate current

- In the first approach, a low voltage DC power is converted into high voltage DC power, and in the second step, this high voltage DC power is turned to AC power.
- In the second approach, a low voltage DC power is converted to low voltage AC power, and then this output is stepped up to high voltage AC power.

In both cases, the use of an additional boost converter is needed to obtain the desired AC output; this results in a decrease in the overall efficiency and increases in the cost of the whole electric system.

4.2 Traditional Voltage Source Inverter

A traditional Voltage Source Inverter uses a combination of switches to convert DC into AC; it uses power electronics to control the switching frequency of the switches and the output. The ideal output of an inverter is a sine wave. However, the output is seldom ideal and often, the output is in the form of either square wave or PWM.

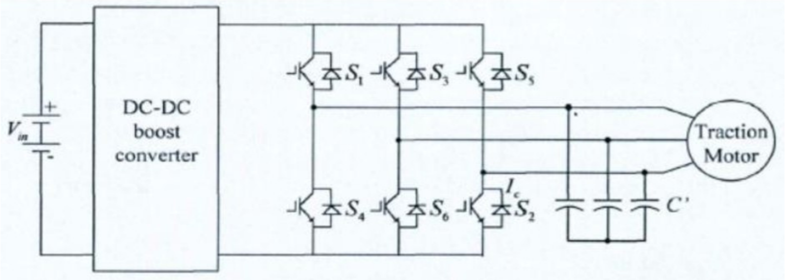


Fig. 12 Traditional V-Source inverter

4.2.1 Traditional VSI Working

The primary circuit consists of six switches, and each is composed of a semiconductor and a diode, which enables it to provide a uni-directional voltage and bi-directional current flow capability. The VSIs are widely used; however, they have certain limitations. The output AC Voltage at the fundamental frequency is limited. Traditional VSI can only work as a buck inverter due to its construction topology. Simultaneous switch-on operations in one leg are not possible as it creates a short-circuit, and high voltage is applied to the electric motor. To prevent shoot-through, a dead time is added which helps in better current communication between upper and lower switches in the same leg. However, the addition of dead time causes torque ripples, harmonics, and switching losses.

4.3 Z-Source Inverter

A Z-source inverter is a unique inverter architecture featuring an impedance network in the shape of the English alphabet ‘X.’ as shown in Fig. 13. A Quasi Z-source Inverter incorporates an LC impedance network between the inverter and power supply. Due to the presence of an LC passive network, QZSI can perform boost function, which is not possible in traditional VSIs. The system also effectively suppresses the voltage ripples than the capacitors in traditional VSIs.

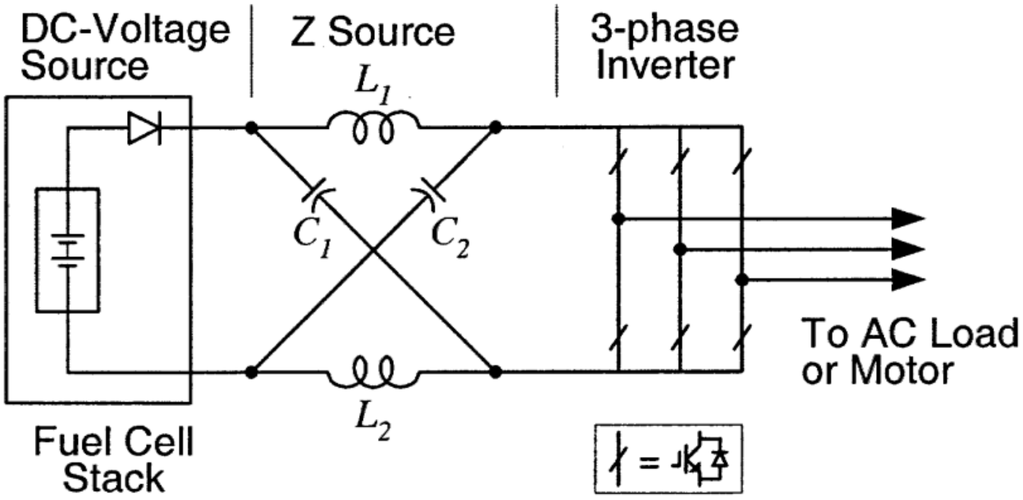


Fig. 13 Z-source inverter [13]

4.3.1 Working of Z-source Inverter [13]

A Z-source inverter can be operated into three working modes based on the switching states of the switches

Mode 1 – Non-Shoot Through Mode

When the inverter bridge is working in an active state, the DC voltage appears across the inductor and capacitor, the capacitor is charged, and the energy flows through the inductor to the load discharging the inductor. [13]

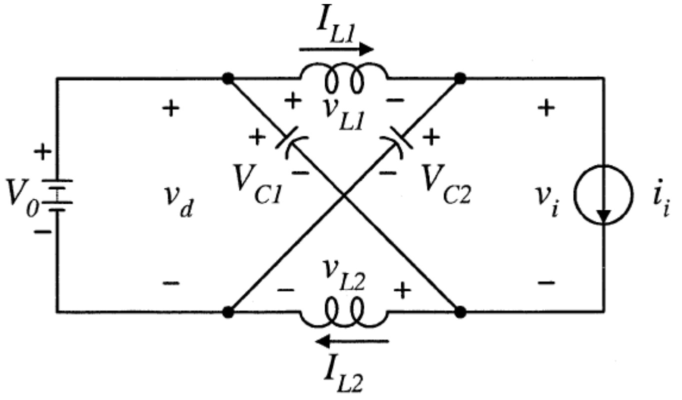


Fig. 14 Z-source inverter non-shoot through mode [13]

Mode 2 –

The Inverter bridge operates in zero states, and the load is short-circuited by the bridge either through the upper or lower three switches. The bridge is viewed as a current source but with zero current flowing through it. The Equivalent circuit for Mode 2 is the same as Mode 1 and shown in Fig. 14.

Mode 3 – Shoot Through Mode

The Inverter bridge operates in Shoot Through Mode. Like in a zero-state operating condition, no voltage appears across the load, the shoot through mode enables the Z-source inverter to work as a boost converter for the voltage of the source. The boost value of the incoming voltage can be regulated by controlling the shoot through duty ratio.

Although the DC Source is separated from the inverter by a diode, voltage across the capacitor instead appears across the inductor, therefore charging it.

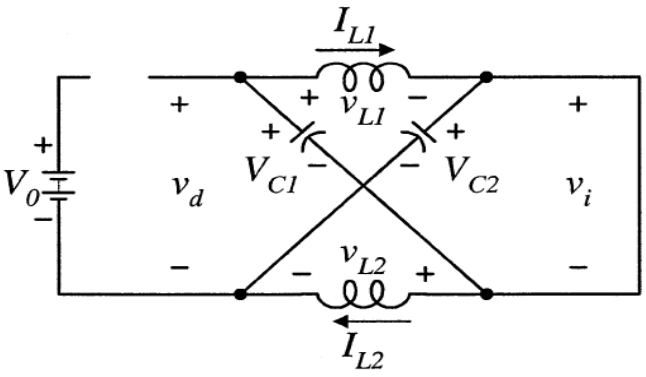


Fig. 15 Z-source inverter shoot through mode [13]

The Diode present on the bridge is forward biased during modes one and two and reversed biased during the shoot through operation.

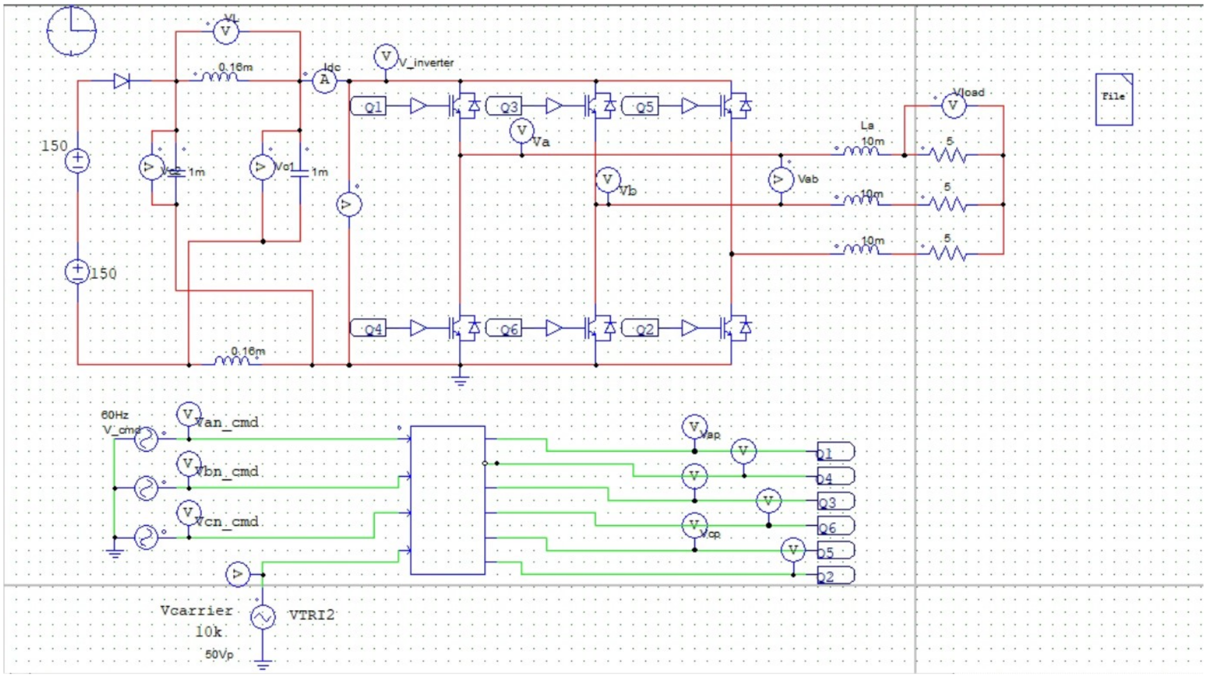


Fig. 16 Z-source inverter PSIM model

4.4 Sinusoidal Pulse Width Modulation (SPWM)

The most widely used strategy for the controlling of the inverters for industrial applications is Pulse Width Modulation (PWM). In this method, a reference copy of the desired sine wave is compared with a much higher frequency triangular carrier waveform**.** [12] The gate pulses of switches can be generated by this comparison. The width of each pulse can be varied with the variation in amplitude of the reference sine wave with the output waveform frequency being the same.

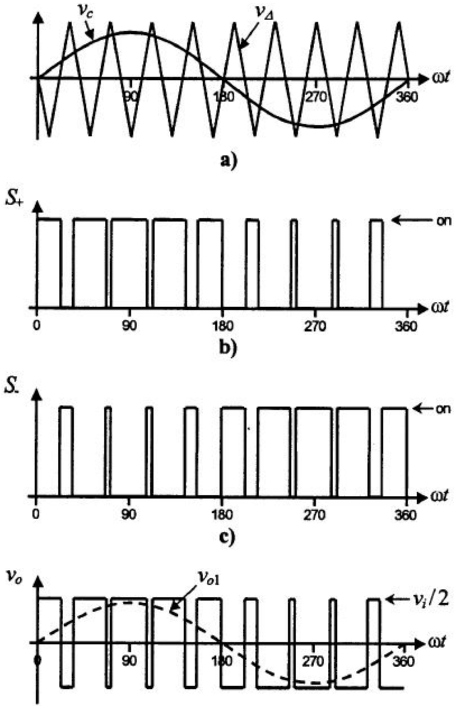


Fig. 17 Sinusoidal pulse width modulation

Chapter 5: Z-Source Inverter Structure with Super Capacitor

5.1 Introduction

With the increase in the popularity of electric vehicles in the last decade, power electronics have played a prominent role in increasing the overall efficiency and durability of the electric drivetrains. The use of high capacity DC batteries and highly efficient 3 phase AC motors have become the most common combination for use in electric vehicles. Motors being up to 95% efficient and with batteries being able to hold up to hundreds of kilowatt-hours of energy, the overall system efficiency can be significantly affected by the inverter and its ability to transform direct current from the battery into the motor usable alternate current. A conventional VSI can perform this operation and can act like a buck (step down) converters for dc-to-ac conversion.

With the introduction of 'regen' capability in the electric vehicles, the power flow between the motor and batteries becomes bi-directional, this resulted in a demand of inverter that was capable of stepping down the voltage when power flow is from battery to motor and performing as a boost converter when the power flow is reversed.

The Z-source inverter is suitable for this application, mainly because of the following reasons.

1. More control parameters than traditional inverters

   The traditional inverters have only one control parameter to control the output AC voltage, while Z-source has two different independent parameters, namely, shoot-through duty cycle and modulation index. The Z-source inverter can behave as a buck or boost converter depending upon the shoot-through duty cycle length. At the same time, the modulation index allows the ability to produce any desired AC voltage, which can be used to regulate the battery's state of charge level and control the power delivery.

2. The Z-source inverter delivers the same functionality as of a DC-DC boost inverter, without the increased complexity in structure and is thus more cost-effective.
3. The ability to perform shoot through without damaging the inverter provides an enhanced durability aspect.

5.2 Proposed Structure and Control Strategy

A new structure for Quasi Z-source inverter with an energy storage device in the form of a supercapacitor is proposed in this section. The main aim of introducing the supercapacitor is to increase the overall durability of the electrical system and to have increased control over the battery parameters such as power delivery and state of charge.

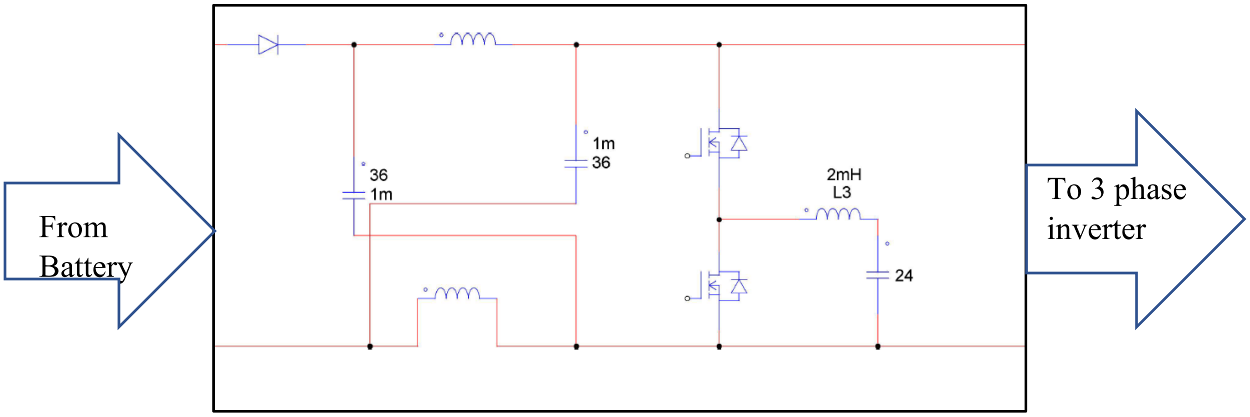


Fig. 18 Proposed Z-source structure with supercapacitor

Theoretically, the supercapacitor can be charged in two ways: by using the battery power or by using the regen power from the motor. The energy stored in the supercapacitor can be used to charge the high voltage DC battery if needed or can be used to supply additional power if required by the AC motor, thus providing increased control over the battery state of charge and motor performance. The supercapacitor can be controlled by controlling the duty ratio of the two MOSFET switches. The shoot-through mode can be achieved by controlling the duty ratios of the MOSFET switches since there will be no need for shoot-through by the inverter side; this provides increased durability and safety in case of short circuit.

To check the feasibility of the prosed structure, a complete model of an electric drive train is built with the proposed inverter structure and is simulated using the PSIM software, and a capacitor is used to simulate the high voltage DC battery with an initial voltage of 36V. To stimulate the charging and discharging of the supercapacitor, a charging current of 1.5A and discharging current of the same magnitude (1.5A) was applied. The initial voltage of the capacitor was selected to be 24V.

5.2.1 Charging the Energy Storage Device

To simulate the charging of the capacitor, a charging current of 1.5 Amps is applied. This is accomplished by controlling the duty ratios and therefore controlling the shoot-through duration of the two switches of the energy storage device. The supercapacitor can be charged when the upper switch is turned on for more time than the lower switch. The charging mechanics of the Energy storage device are shown in Fig. 19. The voltage across the supercapacitor is seen to be increased than the initial voltage assigned to it, confirming that the capacitor is being charged.

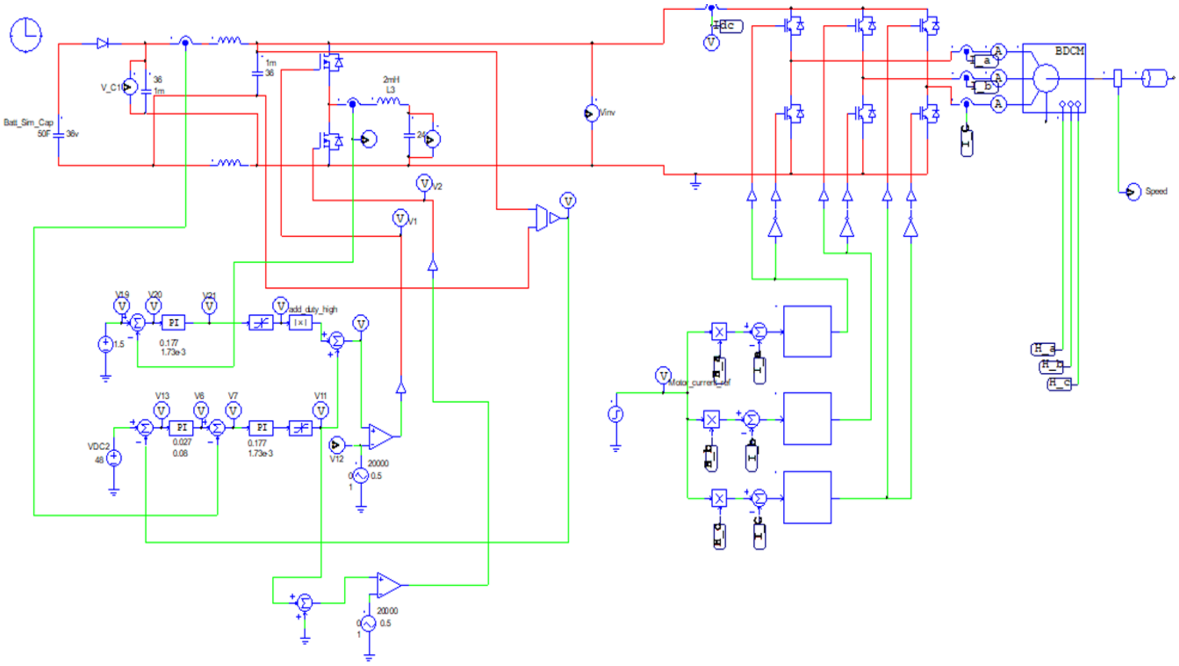


Fig. 19 Charging control strategy for supercapacitor

5.2.1.1 Results

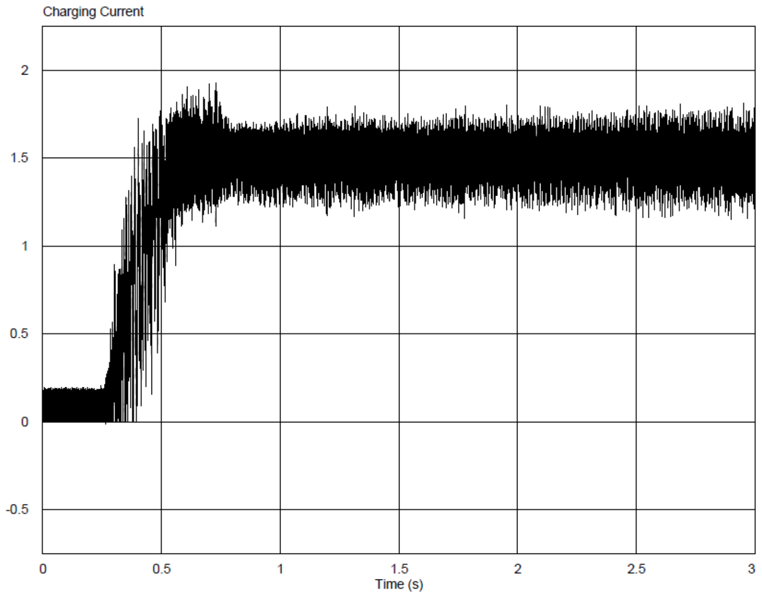


Fig. 20 Charging current applied to supercapacitor

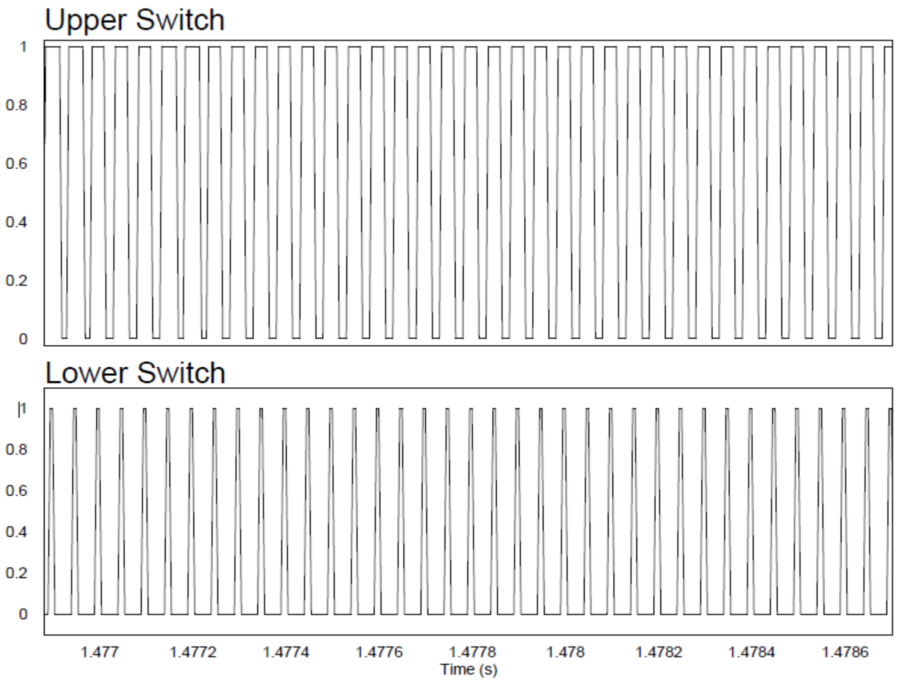


Fig. 21 Switching signals of the upper and lower switches

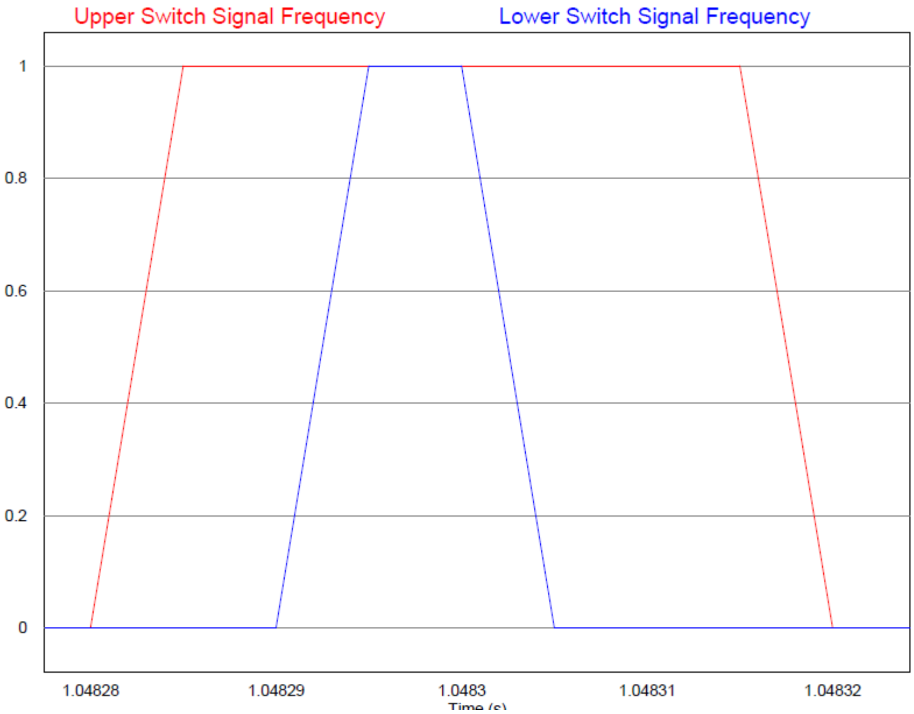


Fig. 22 Overlay of upper and lower switch signal frequency

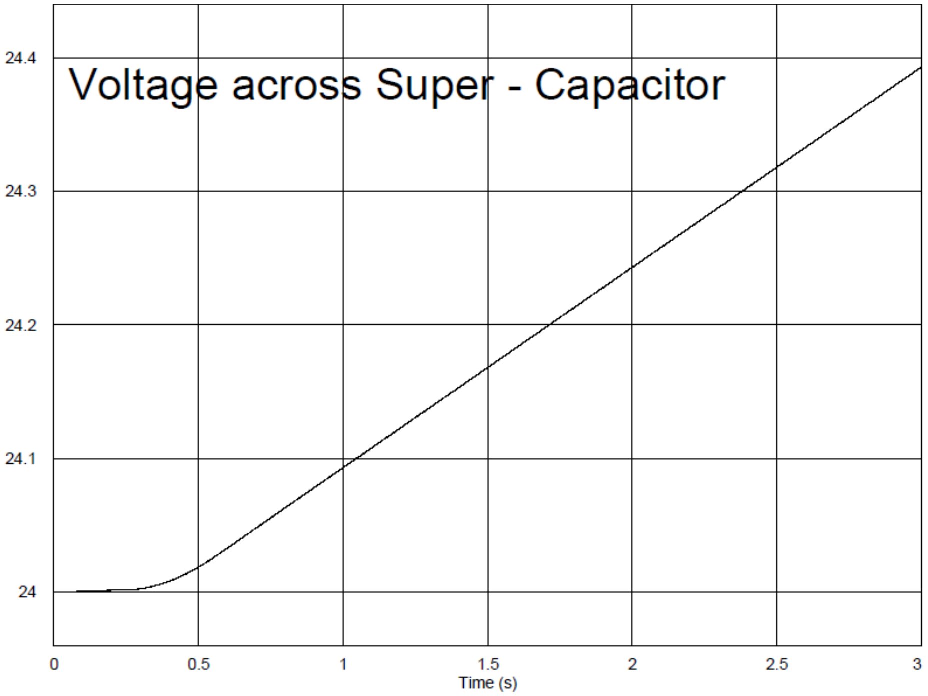


Fig. 23 Increasing voltage across supercapacitor

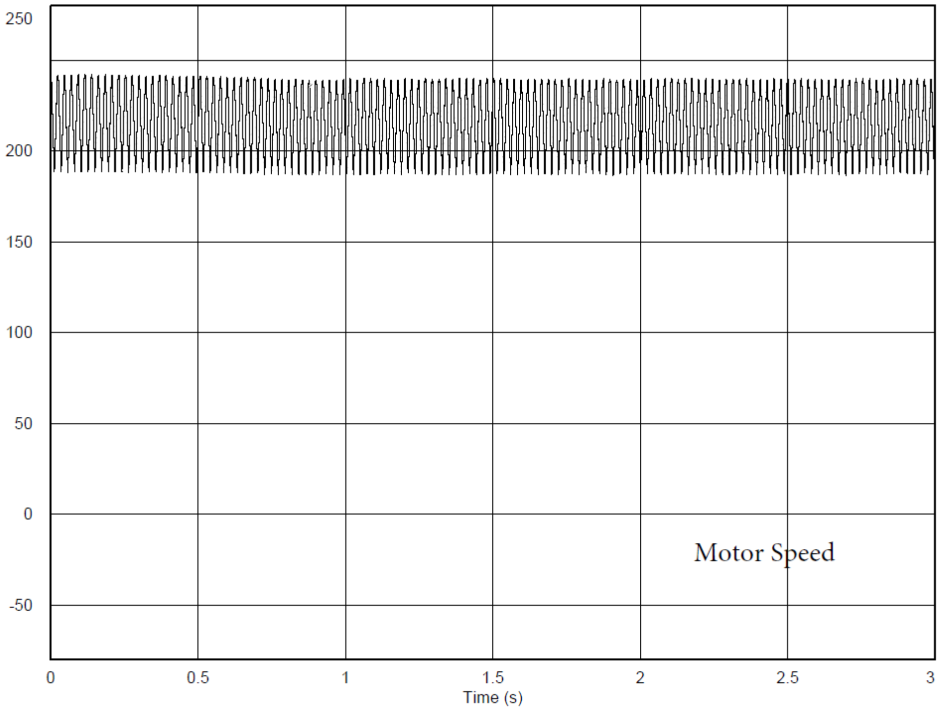


Fig. 24 Motor speed during supercapacitor charging

From Fig. 24 we can see that the charging of the capacitor does not influence the motor speed; this is of essential importance as the addition of an extra element does not affect the performance of the motor.

5.2.2 Discharging the Energy Storage Device

The energy storage device, a supercapacitor, can be discharged if the lower switch duty cycle is higher than that of the upper switch, a discharging current of the same magnitude 1.5 is applied, and the voltage across the capacitor is observed.

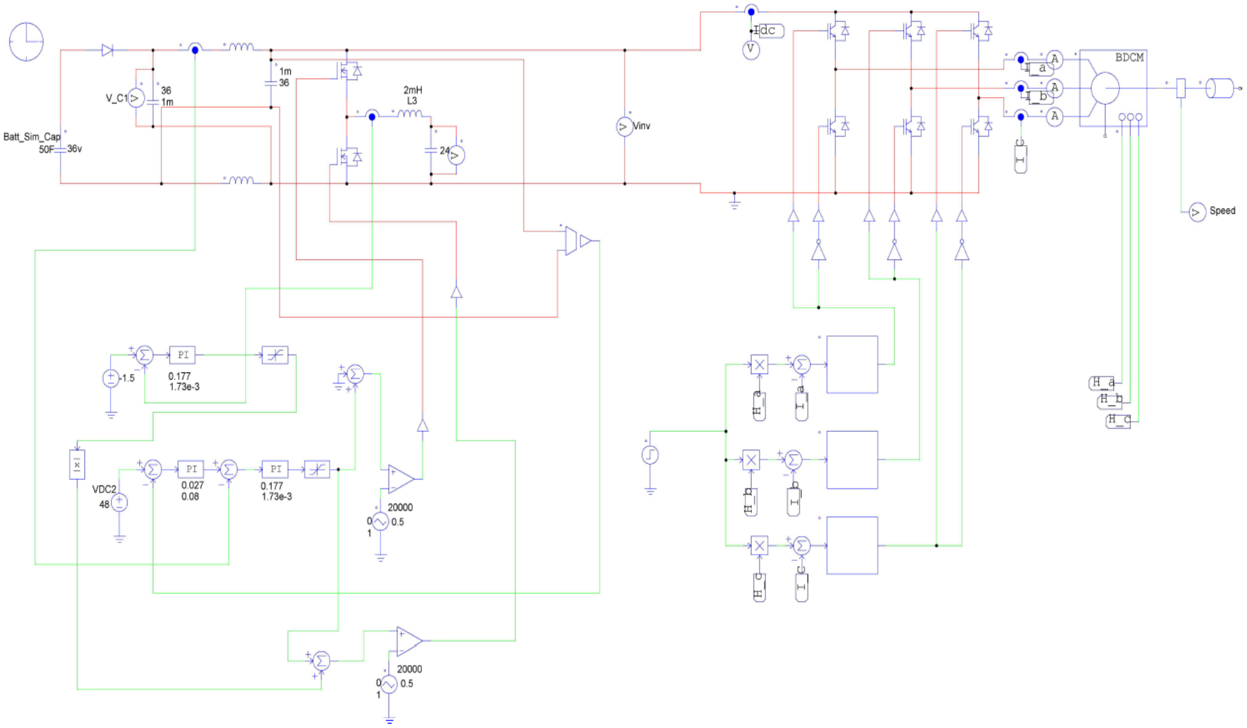


Fig. 25 Discharging control strategy for supercapacitor

5.2.2.1 Results

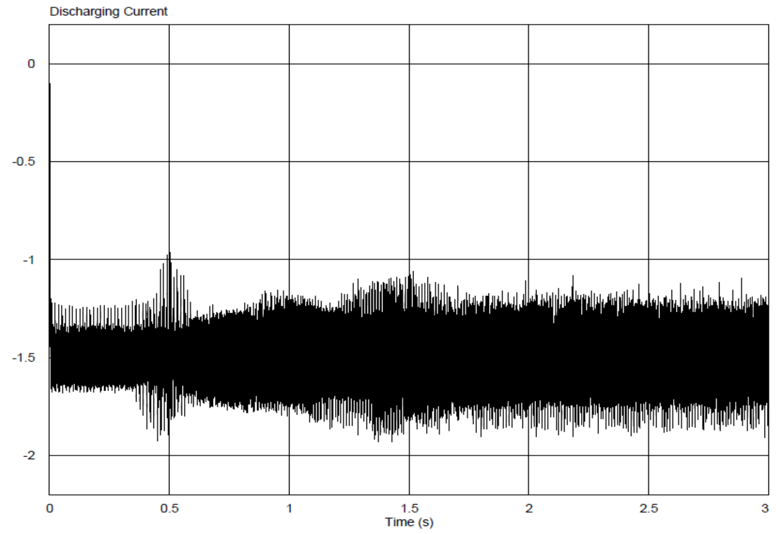


Fig. 26 Discharging current of -1.5A magnitude.

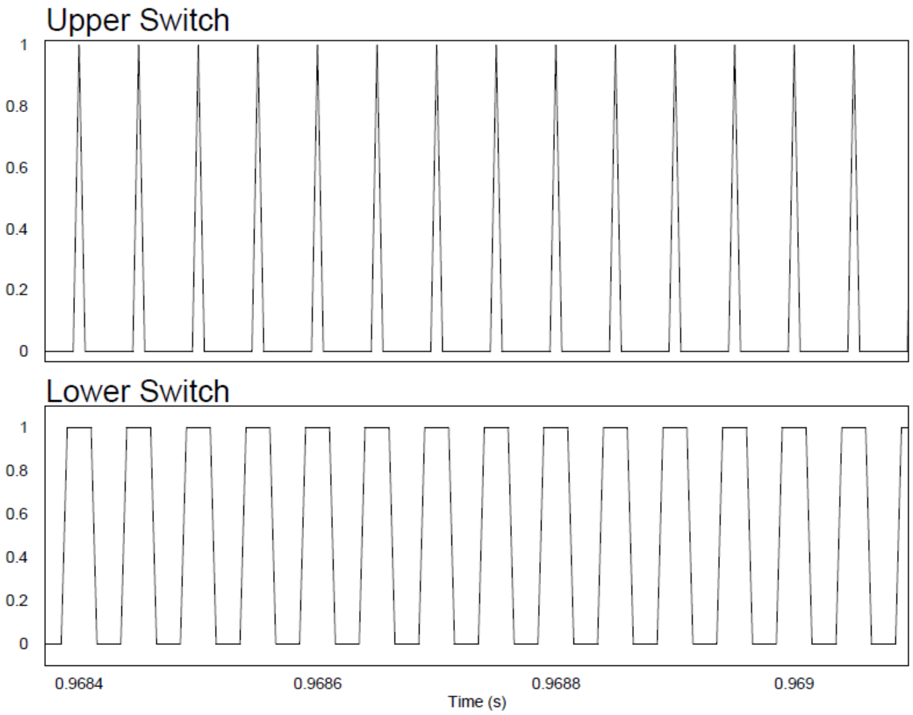


Fig. 27 Switching signals of upper and lower switches (discharge)

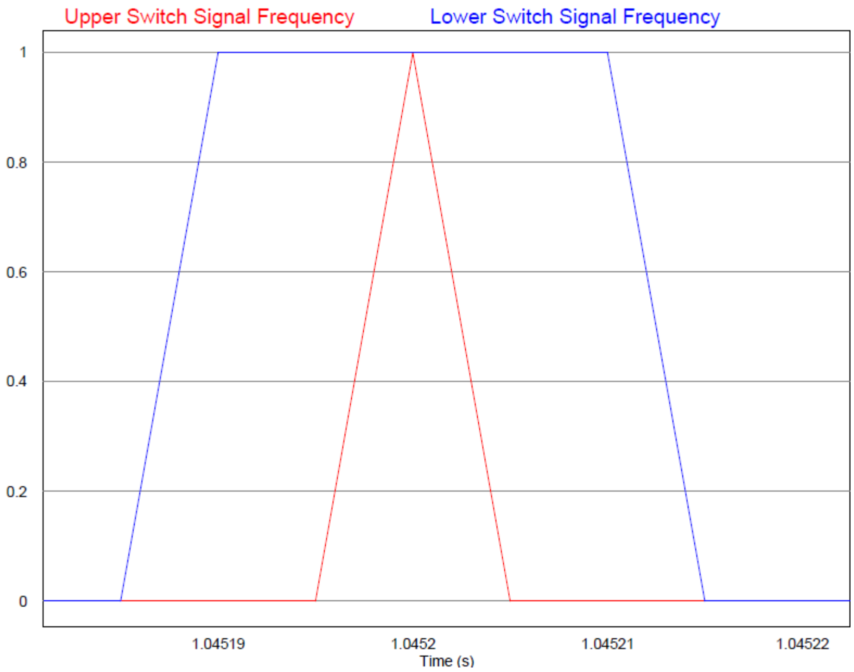


Fig. 28 Overlay of upper and lower switch signal frequency

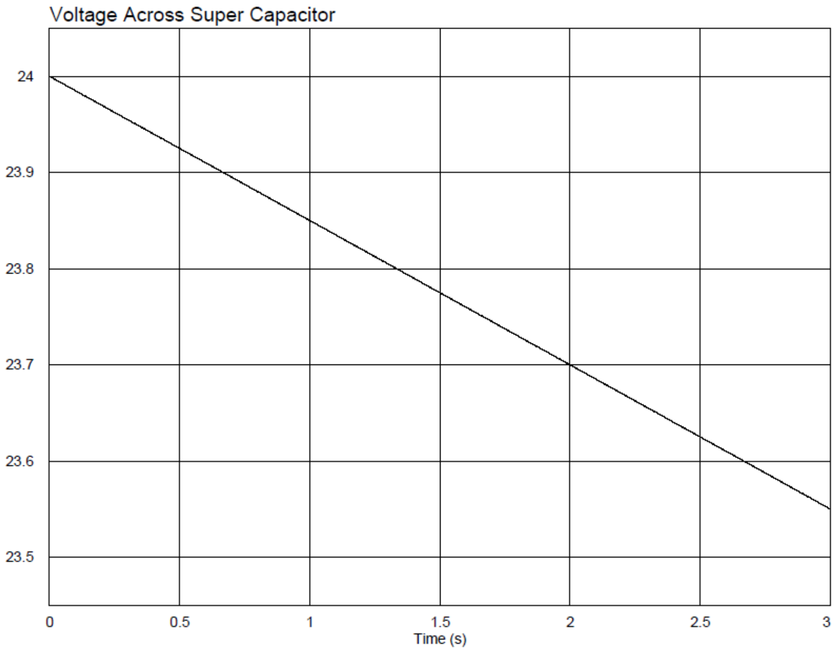


Fig. 29 Voltage across supercapacitor during discharge

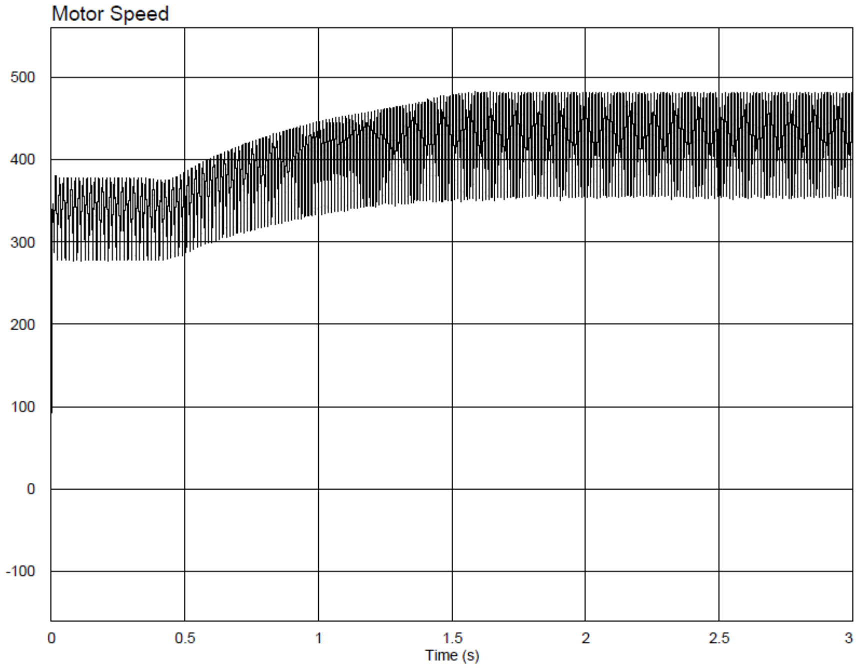


Fig. 30 Motor speed during capacitor discharge

From the above results, it is evident that the motor speed increases as the supercapacitor starts discharging, as mentioned earlier, the torque from a BLDC motor can be controlled by controlling the current delivered to the stator windings, in this case we have limited the current to 5A. The power delivered by the motor is directly proportional to the product of speed and torque produced by the motor, since we have a constant torque increase in speed of the motor will result in increased power by the motor, this validates that the motor performance can be increased by introducing an energy storage device within the inverter architecture.

5.2.3 Combined Structure for Charging and Discharging

In an electric vehicle application, there is no fixed duration for power delivery, and regen, both the parameters are affected by a number of factors that can range from electric limits to natural circumstances; therefore, the models presented here cannot be used in EVs without making modifications. To overcome this challenge, a new structure is developed that combines both the conditions of charging and discharging in one model. This is made possible by introducing a simple C-block in the PSIM and comparing the input current values to be delivered to the supercapacitor, in this case if the current values are of positive magnitude the super capacitor is charged and if the current values are negative the capacitor is discharged. Fig. 31 shows the combined structure and introduction of the C – block governing the charge and discharge of the capacitor.

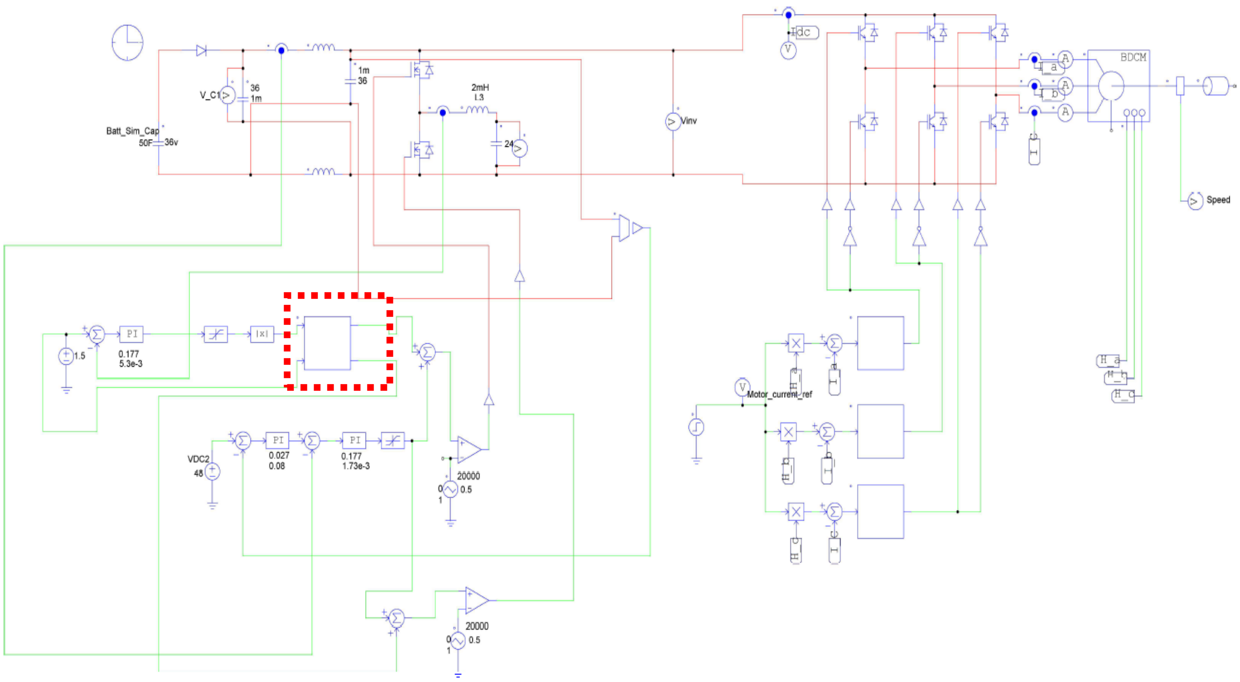


Fig. 31 Control block to regulate the charging and discharging of the supercapacitor

Chapter 6: Conclusion

This research focuses on one of the ways of increasing the efficiency of the electric drive train and providing increased control over battery and power parameters for light electric vehicles. This research proposes an advanced electric inverter with an energy storage device. Based on the simulation model and simulation results experimented in this research, it can be concluded that the proposed structure can indeed increase the overall efficiency of the electric drive train and can be used to improve the performance of the system. As can be seen from the results, the energy stored in the energy storage device can be used to provide increased power to the motor, without any additional load to the battery. The energy storage device can be charged directly from the DC-DC converter while the motor is in the ‘regen’ phase. The ability to perform shoot through by utilizing the two switches of the energy storage device also provide increased durability to the system, as it minimizes any direct damage to the central 3 phase inverter architecture, increasing its overall voltage limitations.

Future Work

In this research, additional charging current and discharging current are applied to the supercapacitor to verify the feasibility of the proposed structure, further study and more time is needed to validate the structure’s response with a full-scale model of an electric drivetrain. In addition to that, the focus of this research has been towards increasing the performance of the 3 phase AC motors from the energy delivered by the Supercapacitor. The energy from the supercapacitor can also be used to maintain the battery state of charge; more research is needed into the development of such a control algorithm and would be the next step to fully utilize the potential of this proposed architecture.

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