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Research Paper on Design of Power-Converters for E-Vehicle Application

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Abstract - *Now a days we are stepping towards the use of E-vehicle and it will rule the roads in future. So, in electric vehicle we are replacing the IC engines with Motors to run the Vehicles. There are various types of motor used in electric vehicles. E.g., Induction Motors, BLDC motors, etc., Our aim is to design the power converters which is used to run induction motor from the battery. The power converters consist of DC-to-DC converter for boosting the DC voltage from the battery and DC-to-AC inverter which converts the DC voltage obtained from the DC-to-DC converter into AC to run the induction motor load.*

***Key Words*: Battery, DC-to-DC converter, DC-to-AC inverter, 3 phase Induction Motor.**

1. INTRODUCTION

EVs first came into existence in the mid-19th century, when electricity was among the preferred methods for motor vehicle propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. To replace ICE, a vehicle is introduced which can run through electricity. For that, the rotational output for the wheels is obtained through a motor. To run that motor, we are in need of the power source, so that we introduced a battery here. As the motor runs in AC, we need to condition the DC supply from the battery, so that we can run that motor at the end. As the motor is in need of high voltage, we need to boost the voltage, so we are using DC – DC converter here. Then the boosted DC voltage should be converted to AC, so we are using inverter (DC-AC converter). Then this AC supply is fed into the motor to run the vehicle.

2. MAIN COMPONENTS OF E-VEHICLE

2.1. Battery

To run a motor we need a source, it may be AC or DC supply. As E-vehicle is a moving one, we cannot connect the vehicle continuously to the grid to give supply to the motor, so we are in need of an inbuilt Battery in the vehicles to give supply to the motor.

2.2. Power Converters

The DC supply form the battery is to be conditioned based on the motor parameters. Here the induction motor is used, so the DC supply from the battery should be converted to the respective AC supply to feed the motor. This role is performed by this Power Converters.

2.3. Motor

To get the mechanical output at the end we need a motor as it is an electric machine which converts the electrical input to the mechanical output. So that we can able to run the vehicle.

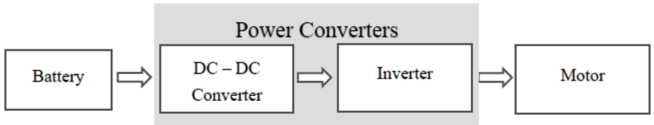


Fig -1: Block diagram

3. PARAMETERS

Table -1: Parameters of the components

Battery	96V – 100Ah Lithium-Ion Battery
Motor	3-phase 4 pole Induction motor – 5 HP – 1430 RPM
DC-to-DC converter (96V DC to 700V DC)	Full Bridge Converter / Push Pull Converter
Inverter	3 – Phase SPWM Inverter

4. POWER CONVERTERS

4.1. DC-to-DC Converter

As the battery voltage rating is 96V, it is not sufficient to run the motor. So, the 96 V DC should be boosted up to 700V DC. Thus, the Full bridge converter or the Push Pull converter is used to boost the voltage level. By considering the power ratings which is above 1KW and isolation purpose, Full

Bridge DC to DC converter and Push pull converter is selected for the operation.

4.2. Inverter

The Boosted DC voltage is converted to AC as the motor is an Induction motor. So, 3-phase SPWM inverter is used to convert this DC voltage to AC voltage which is used to feed the motor. The MOSFET is used for switching purpose as it can switched at the higher frequencies, and the SPWM signal is used as the gate pulse for the inverter switches. Thus, the harmonics are pushed at the higher frequencies so the usage and size of the filter is much reduced.

5. DC-DC CONVERTER

5.1. Topology 1 – Full Bridge DC-to-DC Converter

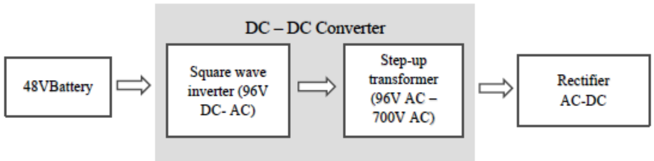


Fig -2: Block Diagram of Full bridge DC-to-DC converter

The 96V battery is fed to the square wave inverter to convert the DC voltage into pulsed AC voltage. Then the square wave AC is stepped up to meet the required volage level i.e.,700V AC by the transformer. Then this voltage is converted to DC again to get 700V DC by using the rectifier.

5.1.1. Circuit Diagram of Full Bridge DC-to-DC Converter

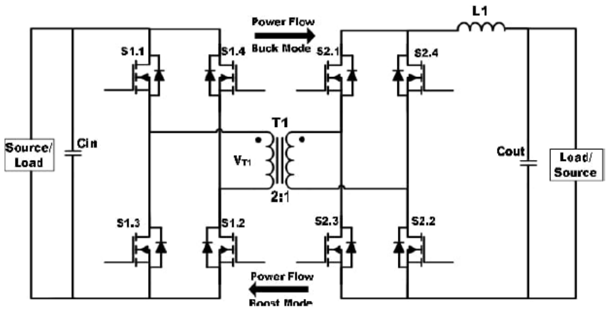


Fig -3: Circuit diagram of full bridge DC-to-DC converter

5.1.2. MATLAB Simulation of Square wave Inverter

The square wave inverter consists of 4 MOSFET switches which are switched at the high frequencies to get the switched AC pulse with 96V at the end of this inverter. The PWM signal of 20 KHz with 50 % duty cycle is used to switch the MOSFET. Then the output from the square wave inverter is fed as the input to the transformer to step up this voltage.

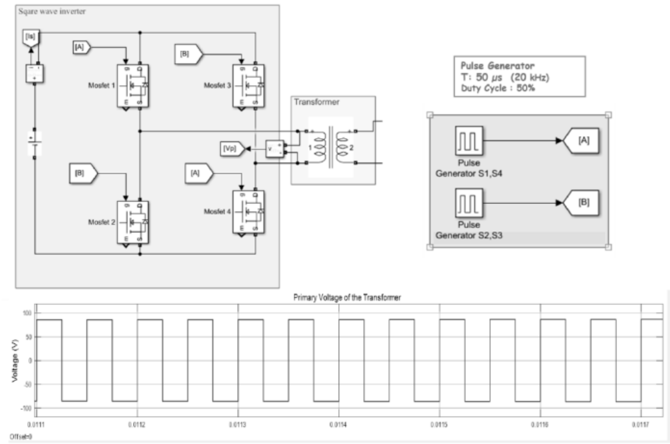


Fig -4: Square wave inverter and output waveform

5.1.2.1. PWM Generation using 555 timer IC

The PWM signal for the square wave inverter is generated by using the 555 timer IC.

DESIGN CALCULATION:

$$f = 1.45/(Ra+Rb)C \qquad T_{HIGH} = 0.69 Ra \times C$$

$$Ra+Rb = 1.45 f \times C \qquad T_{LOW} = 0.69 Rb \times C$$

$$\text{Duty cycle} = (Rb/(Ra+Rb)) \times 100$$

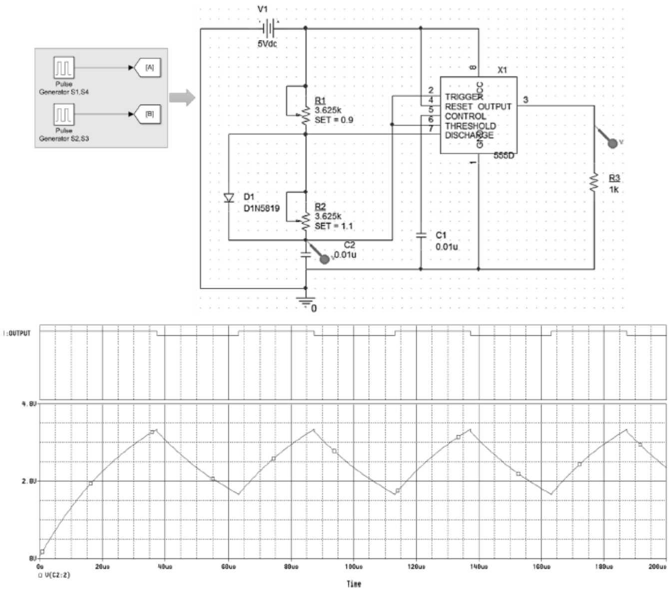


Fig -5: PWM generation using 555 timer circuit and output

5.1.3. Transformer and Rectifier

The 96V AC is stepped up and fed as input to the rectifier by the transformer and then the rectifier converts the AC voltage to the respective DC voltage i.e., 700V.

Ratio of Transformer(k) = $N1/N2 = V1/V2$
k = $N1/N2$ = 96/700
k = $N1/N2$ = 1/8

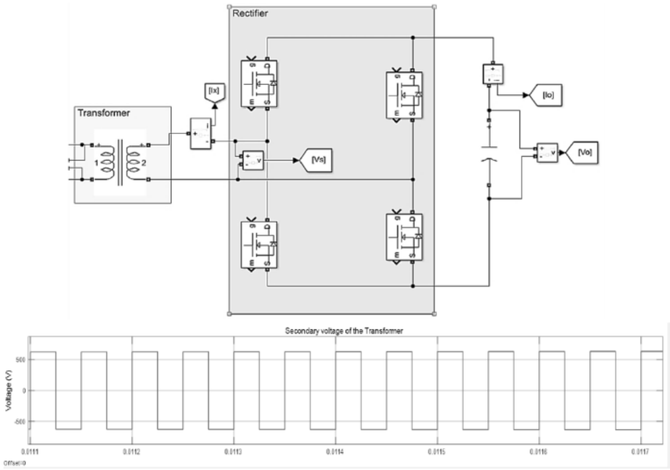


Fig -6: MATLAB model of the rectifier and secondary voltage of the transformer

The wave form is the secondary voltage of the transformer and this waveform is fed into the rectifier so as to get the respective DC voltage as the output.

5.1.4. MATLAB Model of full bridge DC-to-DC converter

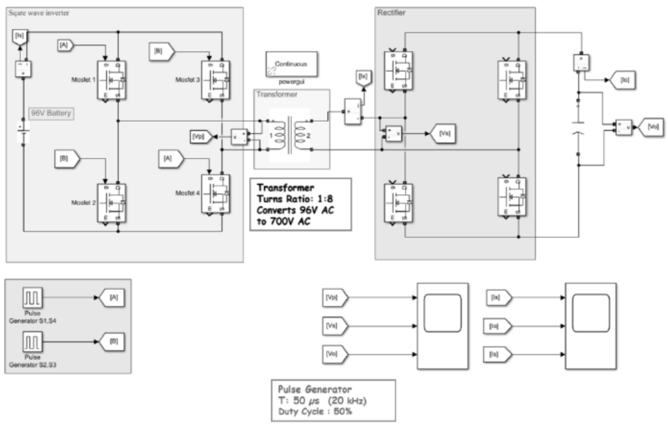


Fig -7: MATLAB model of full bridge DC-to-DC converter

5.1.5. Output waveform of DC-to-DC converter

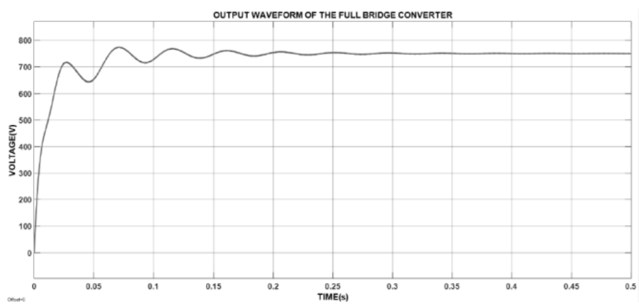


Fig -8: Output waveform of full bridge DC-to-DC converter

From this Full bridge DC-DC converter the respective 700V DC is attained to feed the inverter.

5.2. Topology 2 – Push Pull Converter

Push-pull Converters distinguishing feature pairs of transistors in a symmetrical push-pull circuit, transistors periodically reverse the current in the transformers by switching on and off units. Therefore, current is drawn from the line during both halves of the switching time. With a single transistor working in the same way, but current is drawn half the time, that is difference between buck-boost converters and push-pull converter. So, with this push-pull circuit, push–pull converters have steady input current, create less noise on the input line, and are more efficient in higher power applications.

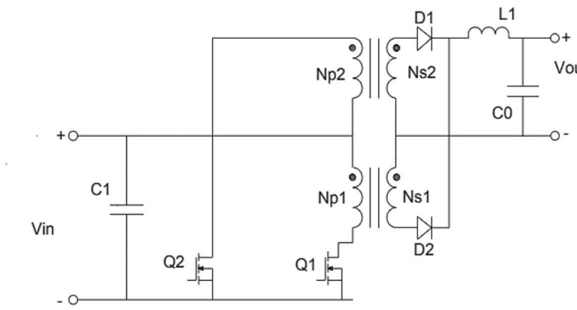


Fig -9: Circuit diagram of Push Pull Converter

A typical push-pull converter contains, 2 transistors as switches (Q1 and Q2), 1 transformer with centre tapped (Np1, Np2, Ns1 and Ns2), 2 diodes as passive switches/rectifiers (D1 and D2), 1 LC filter (CO and L1), 1 input capacitor (C1).

Working: At first half cycle of switching frequency, Supply is given at Vin, Q1 is on and Q2 is off, direction of current is clockwise, Np1 gets charged, Ns1 and Ns2 also will get charged due to induction. D1 will get forward biased and D2 will be reverse biased. LC filter will smooth the output voltage and ripple to a purer DC form output voltage. At second half cycle of switching frequency, Q1 is off and Q2 is on, direction of current become counter clockwise, Np2 gets charged, Ns1 and Ns2 will keep inducing. But direction of current will be reversed, D1 will get reverse biased and D2 will get forward biased. LC filter will carry the filtering function as mentioned above.

Two transistors Q1 and Q2 keep on and off periodically and repeatedly in every period so we can get steady and regulated output voltage. However, the most important is that two transistors must never be closed simultaneously, they will damage if they get closed together. Thus, in our project we implemented the dead band for avoiding this problem. But power ratings of the switches and diode should be chosen twice the respective input voltage and output voltage so as to maintain the circuit to work properly otherwise the switches and diodes will be damaged.

5.2.1. Design Calculation

Table -2: Design Parameters of Push Pull Converter

Input voltage	96V
Required output voltage	700V
Power rating	4KW
Switching frequency of MOSFET	20KHz

Output voltage equation of Push Pull Converter:

$Vo=2\times Vs \times (N2/N1) \times D$

Duty cycle calculation:

$Vo=2\times Vs \times (N2/N1) \times D$

$D = Vo\times N1/(N2\times 2\times Vs)$

Here, $k= V1/V2 = N1/N2 = 1/8$

$D=46\%$ (Appx)

Load Current:

$Io=Po/Vo$

$Io=7.1428A$

So, ripple current:

$\Delta I_L=46\%$ of Io

$\Delta I_L=3.2857A$

Inductance calculation:

$L=(Vo-Vi)\ D/(\Delta IL\times f)$

$L=4.22mH$

Capacitance calculation:

$C= \Delta I_L/(2\times f\times \Delta Vo)$

$C=821.425\mu F$

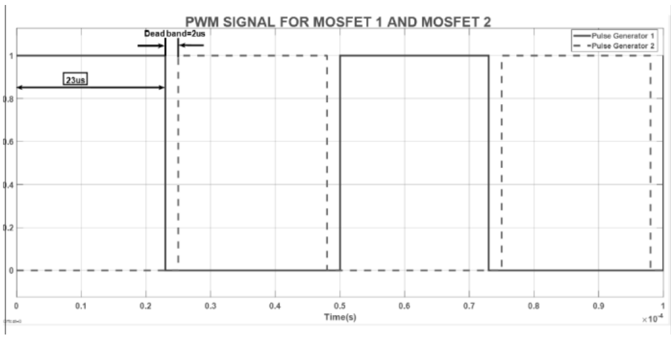


Fig -10: PWM signal with 46% duty cycle

5.2.2. MATLAB Model of Push Pull Converter

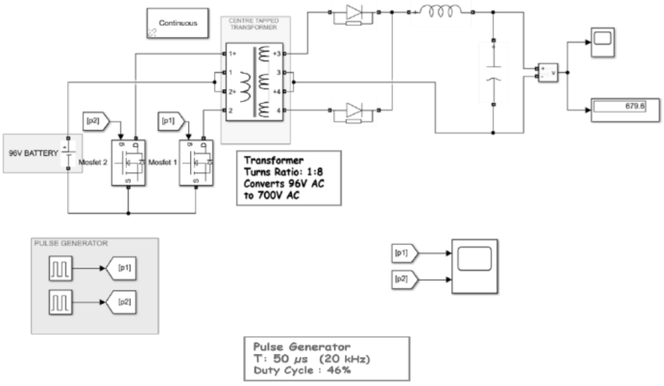


Fig -11: MATLAB model of Push Pull Converter

5.2.3. Output Waveform of Push Pull Converter

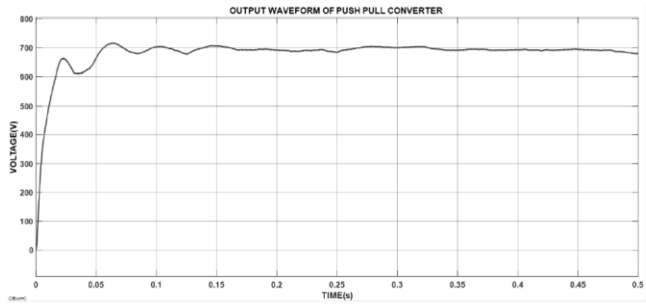


Fig -12: Output Waveform of Push Pull converter

From this Push-Pull converter nearly 700V DC is obtained to feed the inverter.

6. SPWM INVERTER

The 700V DC voltage obtained from the DC-DC converter is fed into the inverter to get the respective 3-phase 400V RMS which is used to drive the 3-phase induction motor. The rms magnitude of line-to-line voltage (fundamental component) output by the inverter will be equal to (√3/2√2) x Edc = 0.612Edc.

6.1. Circuit Diagram of Inverter

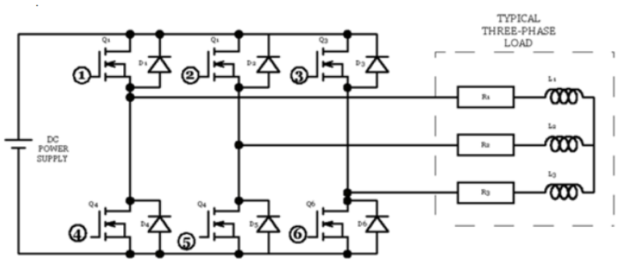


Fig -13: Circuit diagram of 3-phase inverter

6.2. SPWM Signal Generation

The voltage source inverter that use PWM switching techniques have input voltage as dc which is constant in magnitude. The inverter converts dc voltage into ac voltage, where the magnitude and frequency can be controlled. There are several techniques of pulse width modulation (PWM). The efficiency parameters of the inverter such as switching losses and harmonic reduction are principally depend upon the modulation technique. The SPWM (sinusoidal pulse width modulation) is designed based on controlling the inverter's output voltage and output frequency according to the sine functions. SPWM switching technique is widely used in industrial applications or battery electric vehicle applications. SPWM technique are characterized by constant amplitude pulse with different duty cycles for each period. The width of the pulse is modulated to obtain the controlled output voltage of the inverter and to reduce the harmonics content. This technique is widely used in motor control and inverter application.

AMPLITUDE MODULATION INDEX =
SINE WAVE PEAK AMPLITUDE/
TRIANGULAR WAVE PEAK AMPLITUDE

AMI ∝ OUTPUT VOLTAGE

6.2.1. Generation of Sinusoidal Pulse Width Modulation

In SPWM technique three sine waves and high frequency triangular waves are used to generate the PWM signal. Generally, these three sine waves are used for the inverter and these waves are called reference signal and they have 120° phase difference with each other. The frequency of the sinusoidal waves is chosen based on the required inverter output frequency (50/60 Hz). The carrier triangular wave is usually a high frequency wave (in several KHz). The switching signal is generated by comparing the sine waves and triangular wave. The comparator gives out a pulse when the sine magnitude is greater than the triangular magnitude and this pulse is used to trigger the respective switches. In order to avoid undefined AC output in VSI, he switches of any leg cannot be turned off simultaneously.

Triangular wave Frequency = 3 KHz,
Sine wave Frequency = 50 Hz
AMI = 0.5<1

Design of LC Filter:

$fc \leq (1/10) \times fsw$
$fsw = 3000Hz$
$\boldsymbol{fc = 300Hz}$
$L \leq (0.03 \times Vinverter)/(2 \times \pi \times f \times I_{Lmax})$
$L \leq (0.03 \times 230\sqrt{2})/(2 \times \pi \times f \times 50 \times 10)$
$L \leq 0.003106$
$\boldsymbol{L \leq 3.1mH}$
$C = 1/(2\pi fc)2 \times L$
$C = 1/((2\pi \times 300)2 \times 3.1)$
$\mathbf{C = 90.78\mu F}$

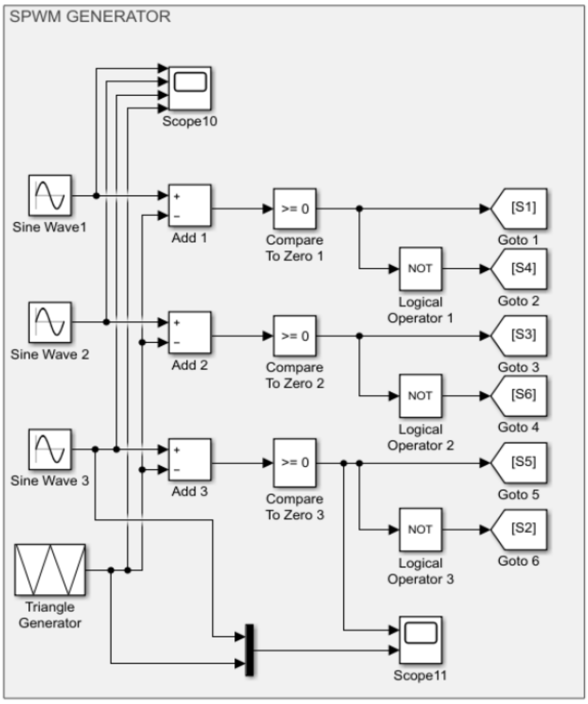


Fig -14: SPWM Generator

6.2.1. Gate Signals of the Inverter Switches

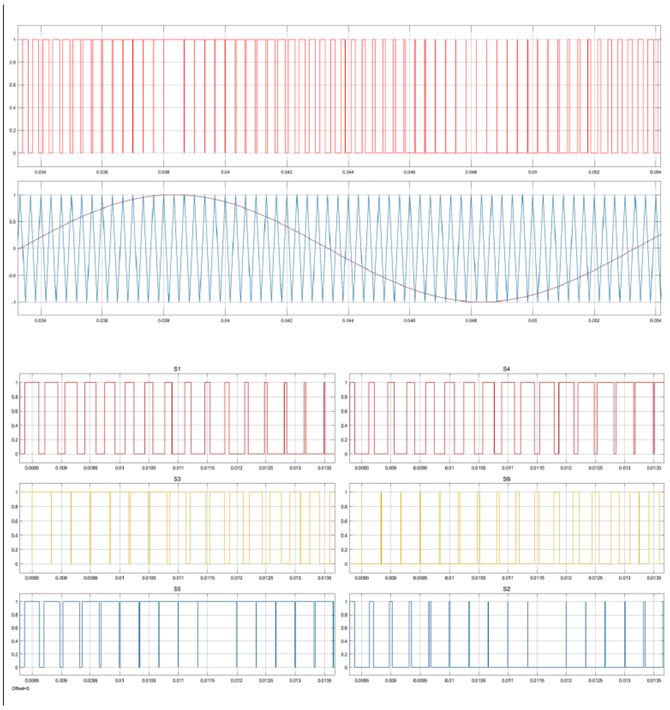


Fig -15: Gate Signals of the inverter

The above pulses are given as the gate pulse for the respective MOSFET switches as mention (i.e., S1-Mosfet 1, S2-Mosfet 2)

6.3. MATLAB Model of SPWM Inverter

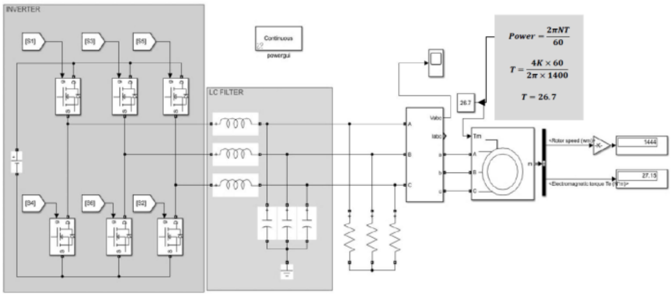


Fig -16: MATLAB Model of SPWM inverter

The DC voltage from the push pull converter is given as the input and then the switches are switched with the SPWM signal at high frequency to get the desirable output and the LC filter is used to eliminate the harmonics.

6.4. Output Waveform of the inverter

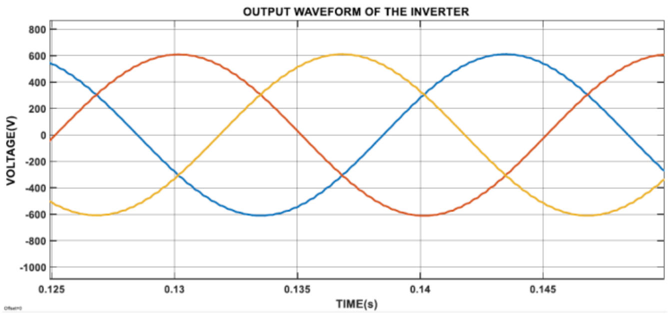
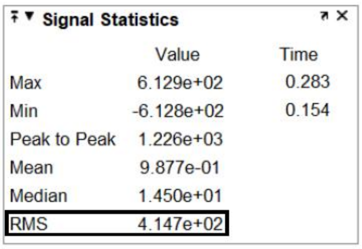


Fig -17: Output Waveform of the inverter



Signal Statistics	Value	Time
Max	6.129e+02	0.283
Min	-6.128e+02	0.154
Peak to Peak	1.226e+03	
Mean	9.877e-01	
Median	1.450e+01	
RMS	4.147e+02	

Fig -18: Output voltage value

Thus, the respective RMS voltage (i.e., 415V) is attained from the inverter to feed the motor.

7. CONCLUSIONS

From the model, the 96V from the battery is stepped up using the DC-DC converter as 700V DC and then the SPWM inverter is used to invert the DC voltage to respective 3-Phase 400V AC to run the induction motor and then the respective rated speed (1430 RPM) of the motor is achieved and it can be varied by changing the Amplitude Modulation Index and Frequency Modulation Index of the gate signal (i.e., SPWM Signal) given to the switches of the inverter.

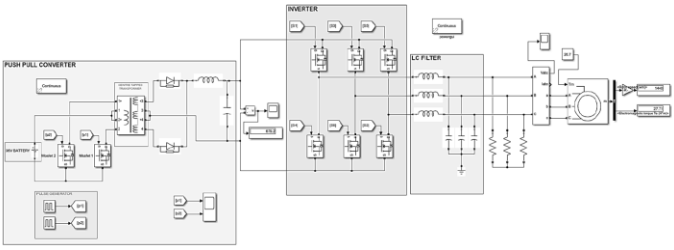


Fig -18: MATLAB Model of Power Converter for E-Vehicle

Table -3: Observation of the speed control of the Motor

MODULATION INDEX	THEORETICALLY CALCULATED SPEED	ATTAINED SPEED
1	1430	1440
0.9	1287	1297
0.8	1144	1196
0.75	1073	1075
0.6	858	857
0.5	715	700

Hence, the speed control of the motor is also attained by changing the Modulation Index of the SPWM pulses.
Though the full bridge converter also can deliver a respective output voltage, the Push-Pull converter is used for the operation by considering the number of components used is less in Push-Pull converter.

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