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Improve Performance of Electric Vehicles with the 5-level Inverter and Energy Efficient Electric Machines

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Abstract: *The number of electric vehicles (EVs) on the road will rise dramatically over time on a global scale. Because of the enormous number of conventional automobiles on the road today, pollution levels are rising. However, EVs still have some mileage limits. Multilevel inverters (MLI) have been a major topic among researchers in recent years. Because there are few advantages to having superior power quality. Essentially, an inverter is a converter that can convert DC electricity to AC power at a specific level. A voltage source inverter can provide two levels of output. At the required voltage level, the MLI can create sinusoidal output voltage and reduce Total Harmonic Distortion (THD). When we raise the voltage, the output power quality improves, and the THD decreases. The development and analysis of a cascaded MLI with reduced THD are suggested in this study. In this paper, a 5-level inverter is used as an MLI.*

The electric machines are where the power loss of the electric powertrain happens. The electric machine used in an electric vehicle is the electric motor. The electric vehicle is an important area of research in the world's modernization path. Currently, research on an electric car is focused on increasing the battery's energy density, improving the electric powertrain efficiency, and reducing the battery's charging time. The performance of EVs with energy-efficient electric machines is examined in this literature study.Researchers analyze the efficiency, losses, cost, torque, and dependability of switched reluctance motors (SRM), induction motors (IM), three-phase permanent magnet synchronous motors (PMSM), and PM brushless DC machines to find the best electric motor drives for electric vehicle applications (PMBLDC). As a result of these studies, several conclusions have been formed. According to the research, PMSM motor drives are the preferred choice for electric vehicles. This motors are fed by various power electronic converters such as DC-DC converters and DC-AC converters.

Keywords: *Electric vehicle, electric machine, DC-AC converter, power loss, efficiency.*

Nomenclature

Evs	Electric vehicles	$i_{cd,}i_{cq}$	d-, q-axis iron loss current components
MLI	Multilevel inverter	$i_{0d,}i_{0q}$	d-,q-axis magnetizing current components
THD	Total harmonic distortion	$i_{d,}i_{q}$	d-, q-axis current components
PMSM	Permanent magnet synchronous motor	$L_{d,}L_{q}$	d-, q-axis inductance components
IM	Induction motor	R_a	Armature resistance
SRM	Switched reluctance motor	ψ_f	Flux linkage due to the rotor magnets
PMBLDC	PM brushless DC machines	ψ_q	q-axis components of the stator flux
FCEV	Fuel cell electric vehicle	ψ_d	d-axis components of the stator flux
SCs	Supercapacitors	ω	Stator current frequency
FCs	Fuel Cells	p	Number of pole pairs
VA	Volt-Ampere	R_c	Equivalent iron resistance
MVA	Mega Volt Ampere		

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I. INTRODUCTION

EVs play a vital role globally in the transportation system in terms of availability of fossil fuel, pollution, and cost of fuel. EVs consist mainly the inverter and electric motors. Nowadays the accessibility of power rating of inverters is from certain Volt-Ampere (VA) to several Mega Volt Ampere (MVA), and they are used for continuous power supply, an electric substation, and at home [1-5]. An arrangement of numerous single-phase inverters connected in series is known as a cascaded H-bridge MLI. Due to several benefits including high voltage capabilities, good power quality, less magnetic interference, and low switching losses, the cascaded H-bridge MLI has emerged as a very interesting and unusual topic for researchers [5–11]. All of the DC voltage sources in an MLI don't need to be equal. When constructing an MLI, we focus on generating a pure sinusoidal output voltage waveform with the least amount of harmonics. Harmonics generated at the output voltage side have a significant impact on power quality [12]. Each H-bridge in a cascaded H-bridge MLI has its DC source. The purpose of this research is to reduce THD at the output of a cascaded H-bridge MLI. The power quality can be improved and the THD can be reduced by controlling the switching angle of switches and using some energy storing element which connected in a particular manner.

Electric motors have various types. In the EV, the motor is used PMSM, PMBLDC, SRM, and IM. Since no single motor can meet all these requirements, EV companies have used various types of motors. Figure 1 represents the main component of the EV. PMSM, PMBLDC, IM, and SRM have been used either in commercial or experimental EVs. All of the motors have benefits and drawbacks, which have been detailed in [13-18]. For nearly a century, electric motors have been employed in traction applications. Primary aspects include high power density for compact size and less weight, highly efficient to reduce energy consumption, highly reliable to reduce maintenance, the ability to operate under overload conditions, and a wide constant power speed range to reduce the need for a variable gearbox between the machine and wheels. Because the operational points of an electric vehicle change constantly during the driving cycle, the design of such devices requires specific consideration. PMSM and PMBLDC have emerged as the ideal types of machinery for electric vehicles in recent years. They both have excellent efficiency and power density, as well as a large constant power rate range, however, PMSM is less expensive than PMBLDC. As a result, PMSM is preferred over PMBLDC in terms of cost perception.

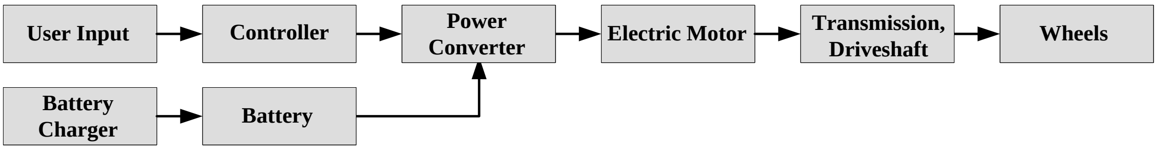


Figure 1. Main component of EV

II. Electric Vehicles Powertrain

As depicted in Figure 2, an EV is a vehicle that uses a combination of energy sources to power an electric drive system, such as Fuel Cells (FCs), Batteries, and Supercapacitors (SCs). The primary energy source of an EV is augmented by one or more energy storage devices. As a result, the system's cost, mass, and volume can be lowered, yet its performance can be greatly improved. Batteries and SCs are two often utilized energy storage devices. They can be connected to the fuel cell stack in several different ways. A basic configuration is to connect two devices (FC/battery, FC/SC, or battery/SC) in parallel. However, because the power drawn from every device is passively governed by its impedance, it cannot be regulated in this way. Temperature, state of charge, health, and point of operation are all factors that affect impedanceAs a result, each device may be used at an unfavorable level, such as in terms of health and efficiency. The utilization of high-power DC/DC converters is required for the EV power supply system, as can be observed. The DC/DC converter's power is determined by vehicle factors such as top speed, acceleration time from 0 to 100 kilometers per hour, weight, maximum torque, and power profile (peak power, continuous power) [19]. The converter power for passenger cars is typically greater than 20 KW and can reach 100 KW [20].

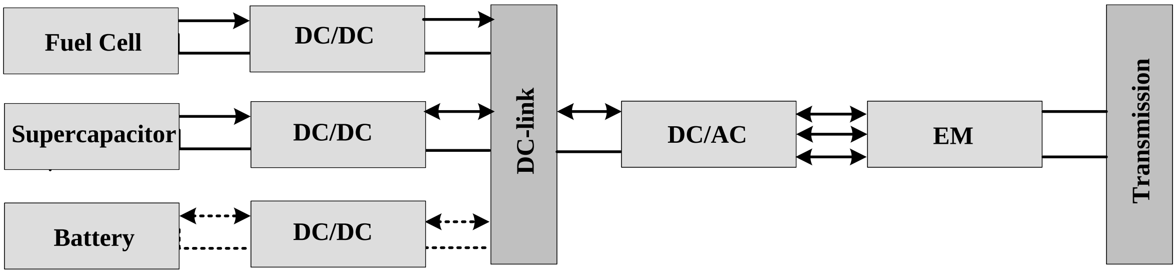


Figure 2. Electrical vehicle drive system

Cascaded H-bridge Multi-Level Inverter (MLI)

MLI, which is especially suitable for application in reactive power compensation, has attracted huge interest in the power industry. 5-level inverters offer greater benefits than conventional 2-level inverters. Because of the higher output voltage level, the AC link voltage harmonics are decreased. There are no voltage balancing capacitors on the input side of the cascaded inverter, and high voltage fast recovery diodes are not required across the power switch. Due to its numerous advantages, MLI can effectively be utilized as a replacement for conventional 2-level inverters in Permanent Magnet AC Motor drives applications. Switching losses are reduced, harmonics are reduced, dv/dt is reduced, common-mode voltage is reduced, electromagnetic interference is reduced, and switch stress is reduced [21-24].

The output percentage of THD nears zero as the number of levels increases to infinity, but the cost of implementing the higher level increases significantly. The challenge of providing the firing pulses for the particular power switches increases as the number of power switches used to form the power circuit increases. This study looks at a 5-level inverter and how energy-storing devices can be connected in a specific way to reduce THD. Annexure Figure 1 depicts the cascaded inverter architecture of single-phase h-bridge cells (full bridge). As we assume equal DC voltage sources, the voltages are referred to as V_{dci} where i =1, 2, 3…m for an inverter with m number of h-bridge inverter cells.

Mathematical Expressions

The Fourier series of the stepped waveform shown in Figure 3 is expressed as.

$$V(\omega t) = \sum_{n=1}^{\infty} V_n \sin(n\omega t) \qquad (1)$$

For symmetric waveforms, Vn is the amplitude of a voltage harmonic of order n; even harmonics don't exist.

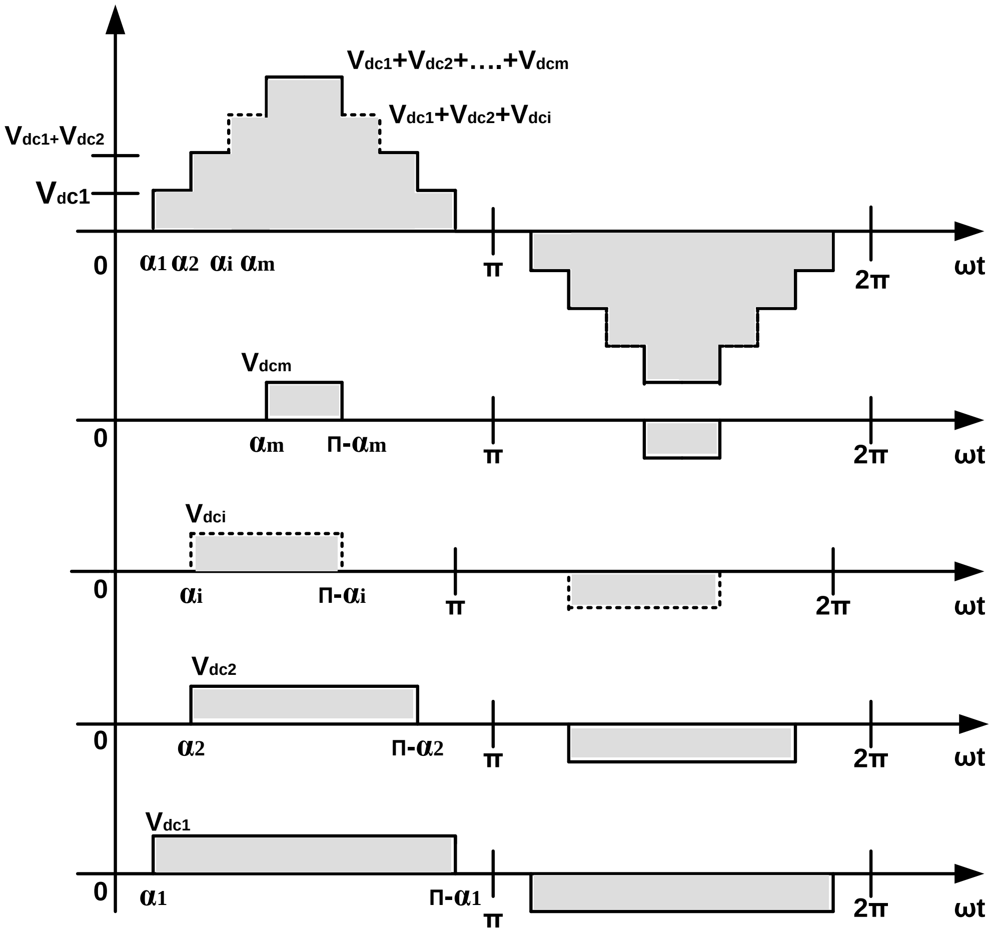


Figure 3. waveform of multilevel h-bridge cascaded inverter

Harmonic voltage V_n is given by,

$$V_n = \begin{cases} \frac{4}{n\pi} \sum_{i=1}^{m} V_{dci} \cos(n\alpha_i), & for\ odd\ n \\ 0, & for\ even\ n \end{cases} \qquad (2)$$

The periodic voltage waveform phase THD can be represented as [25]:

$$\mathrm{THD_{ph}} = \sqrt{\left(\frac{V_{rms}}{V_1}\right)^2 - 1} \qquad (3)$$

where V1 is the fundamental component's RMS value and Vrms is written as [25]:

$$\mathrm{V_{rms}} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} V^2(\omega t)\, d(\omega t)} \qquad (4)$$

A generalised formula for accurate phase THD is derived from basic equation 1 to equation 4 [24],

$$\mathrm{THD_{ph}} = \sqrt{\left(\frac{\pi^2}{8} . \frac{\left(\sum_{i=1}^{m} V_{dci}\right)^2 - \frac{2}{\pi}\left[\alpha_1 V_{dc1}{}^2 + \sum_{j=2}^{m} \alpha_j \left(V_{dcj}{}^2 + 2V_{dcj} \sum_{k=1}^{j-1} V_{dck}\right)\right]}{\left(\sum_{i=1}^{m} V_{dci} \cos \alpha_i\right)^2}\right) - 1} \qquad (5)$$

Switching Sequence

Table 1. Switching sequence of 5-level Inverter

States of IGBT Power Switches								Output Voltage
S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	
ON	ON	OFF	OFF	ON	ON	OFF	OFF	0
ON	OFF	OFF	ON	ON	ON	OFF	OFF	V
ON	OFF	OFF	ON	ON	OFF	OFF	ON	2V
ON	OFF	OFF	ON	ON	ON	OFF	OFF	V
ON	ON	OFF	OFF	ON	ON	OFF	OFF	0
OFF	ON	ON	OFF	ON	ON	OFF	OFF	-V
OFF	ON	ON	OFF	OFF	ON	ON	OFF	-2V
OFF	ON	ON	OFF	ON	ON	OFF	OFF	-V

Table 2. Pulse Width, Delay, and OR operation of 5-level Inverter

Parameters (→) Switch (↓)	Delay	Pulse Width (PW)	OR operation	Delay	Pulse width (PW)
S1	Delay=(0.02/8)*0	PW=(5/8)*100	Yes	NA	NA
S2	Delay=(0.02/8)*0	PW=(1/8)*100	No	Delay=(0.02/8)*4	PW=(4/8)*100
S3	Delay=(0.02/8)*5	PW=(3/8)*100	No	NA	NA
S4	Delay=(0.02/8)*1	PW=(3/8)*100	No	NA	NA
S5	Delay=(0.02/8)*0	PW=(6/8)*100	Yes	Delay=(0.02/8)*7	PW=(1/8)*100
S6	Delay=(0.02/8)*0	PW=(2/8)*100	Yes	Delay=(0.02/8)*3	PW=(5/8)*100
S7	Delay=(0.02/8)*6	PW=(1/8)*100	No	NA	NA
S8	Delay=(0.02/8)*2	PW=(1/8)*100	No	NA	NA

Matlab simulation for 5-level h-bridge inverter

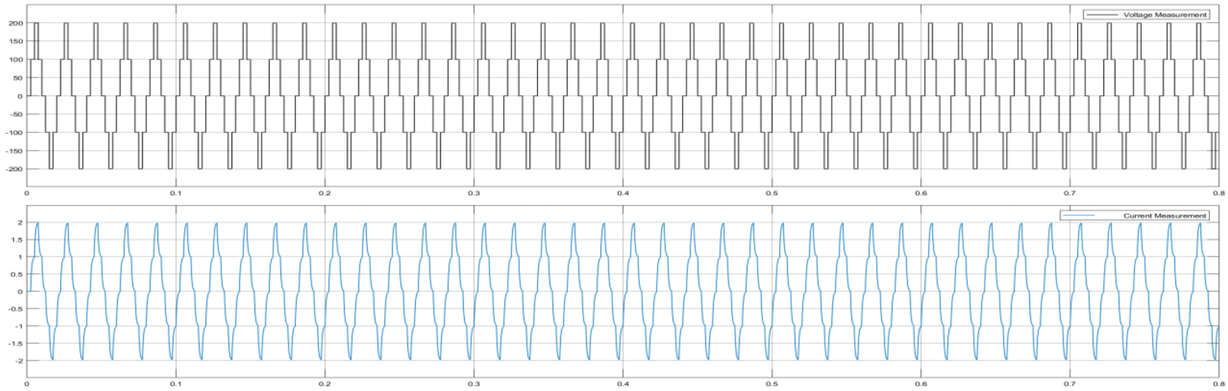
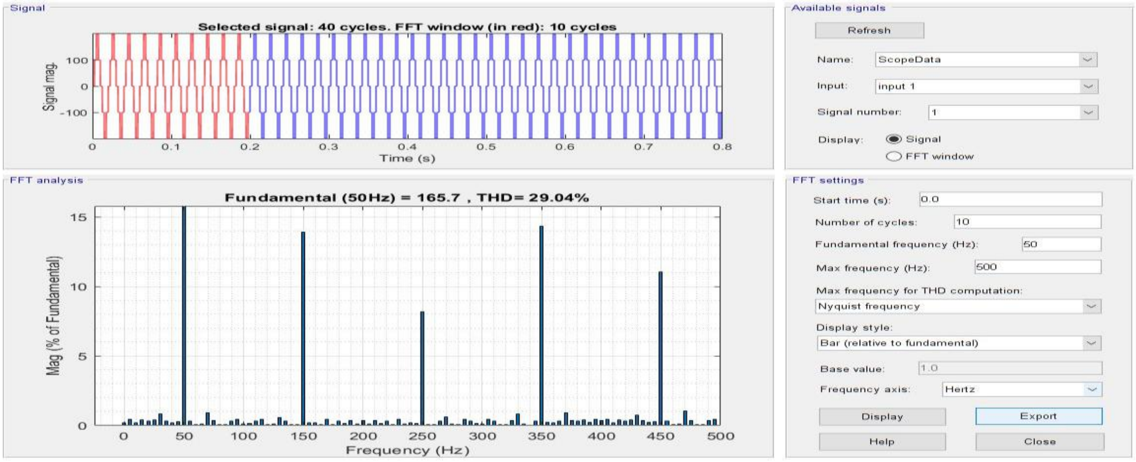


Figure 4. Simulation result of 5-level cascaded inverter without filter



Selected signal: 40 cycles. FFT window (in red): 10 cycles

Fundamental (50Hz) = 165.7 , THD= 29.04%

Name: ScopeData
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 0.0
Number of cycles: 10
Fundamental frequency (Hz): 50
Max frequency (Hz): 500
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 5. FFT analysis of 5-level cascaded inverter without filter

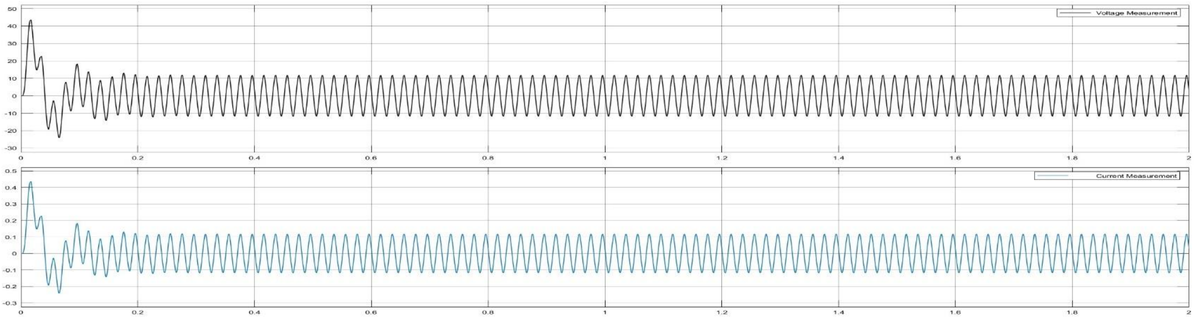
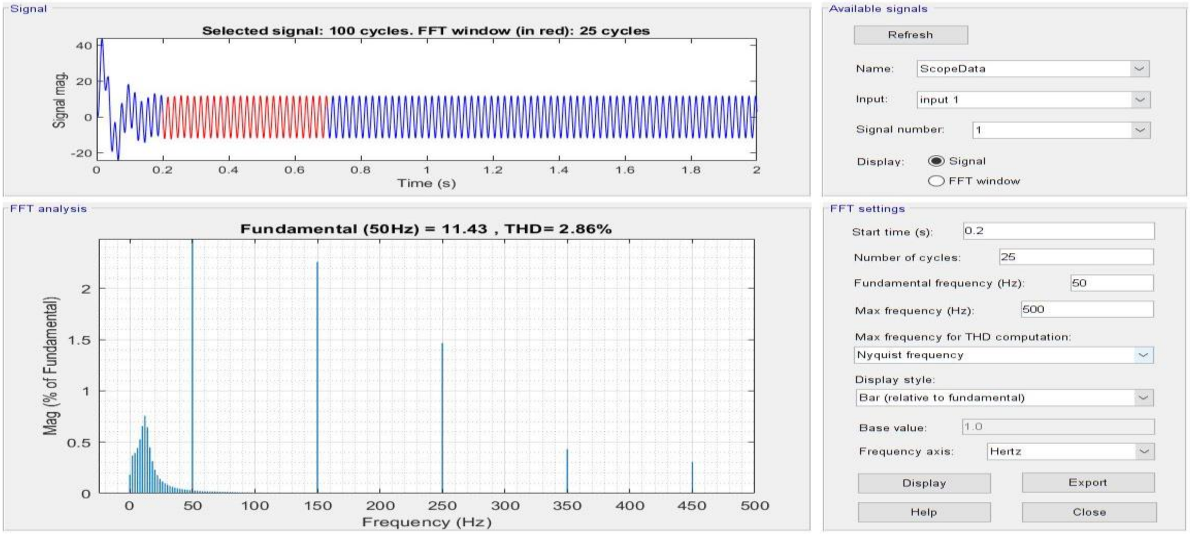


Figure 6. Simulation result of 5-level cascaded inverter with filter



Selected signal: 100 cycles. FFT window (in red): 25 cycles

Fundamental (50Hz) = 11.43 , THD= 2.86%

Name: ScopeData
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 0.2
Number of cycles: 25
Fundamental frequency (Hz): 50
Max frequency (Hz): 500
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 7.FFT analysis of 5-level cascaded inverter with filter

By using some energy storing element (inductor and capacitor) which connected in a particular manner with the multilevel inverter. The THD is reduced significantly from 29.04% to 2.86%.
With the help of this 5-level inverter, the THD is reduced so that the efficiency of the inverter is increased which result in the efficiency of EVs is also increased.

Figure 11 depicts the classification of the AC motors mentioned below. It should be noted that the shaded motor types are allowed for use in EV propulsion technology.

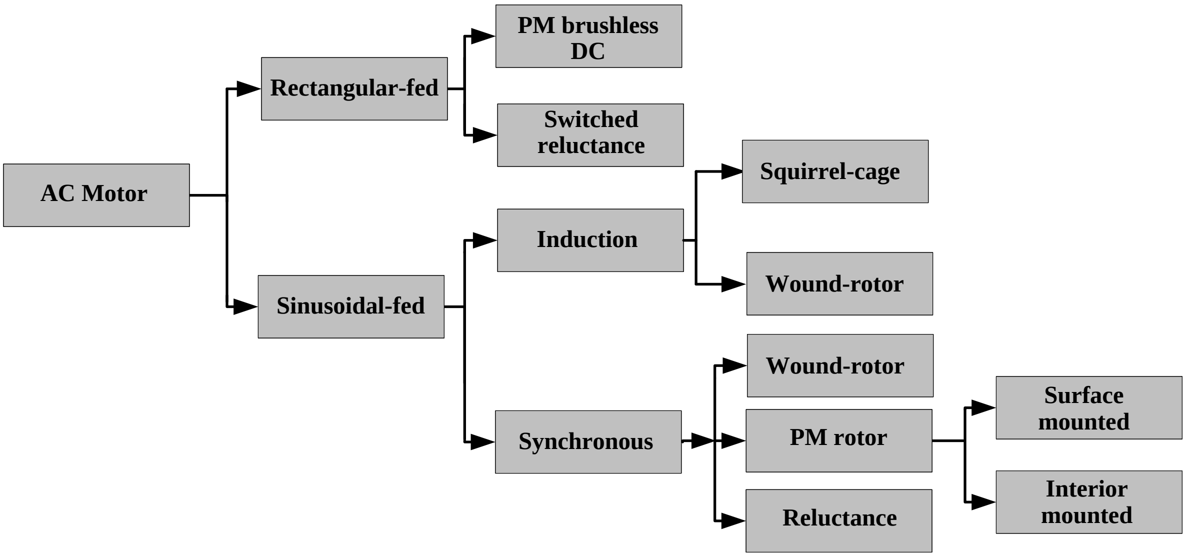


Figure 8. classification of AC motor

A. Permanent Magnet Synchronous Machine (PMSM)

Permanent magnets provide the excitation of the PMSM in the rotor. Because permanent-magnet excitation takes little area, this machine benefits from the high energy density of the magnets. The PMSM has high overall efficiency in the rated speed range because no field current is required. Iron losses, which occur mostly in the stator and may be easily dissipated by a case cooling system, are the PMSM's most significant losses. As a result, in terms of power density and efficiency, the PMSM surpasses the IM.

One of the most significant disadvantages of rare-earth magnets such as NdFeB is their expensive cost. Another downside is the extra current required for field weakening, which results in larger stator losses and lower efficiency at high speeds. Furthermore, the magnet properties limit the overload capacity. High magnet temperatures in addition to high stator currents must be prevented to avoid irreversible demagnetization, necessitating the use of a reliable temperature sensor system. The analytically pre-designed PMSM has a volume of 7.1 dm3 and a power density of 4.2 kW/dm3 and was designed using the in-house software ProMOTOR [26,27] and the design rules in [28,29]. The PMSM is one of the most ideal devices for electric traction drives due to its advantages. Furthermore, reducing magnet costs have made PMSMs more appealing in recent years. PMSM are mostly used for high power ratings.

Mathematical Expression for Torque and Losses

Electromagnetic torque (T_e) is

$$T_e=\frac{3}{2}p(\psi_d i_{0q}-\psi_q i_{0d})=\frac{3}{2}p[\psi_f i_{0q}+(L_d-L_q)i_{0q}i_{0d}] \qquad (6)$$

Iron and Copper losses of the motor is

$$P_{\text{iron}}=\frac{3}{2}R_c\left({i_{cd}}^2+{i_{cq}}^2\right)=\frac{3}{2}R_c\left[\left(-\frac{\omega L_q i_{0q}}{R_c}\right)^2+\left(\frac{\omega L_d i_{0d}+\omega\psi_f}{R_c}\right)^2\right] \qquad (7)$$

$$P_{\text{copper}}=\frac{3}{2}R_a\left({i_d}^2+{i_q}^2\right)=\frac{3}{2}R_a\left[\left(i_{0d}-\frac{\omega L_q i_{0q}}{R_c}\right)^2+\left(i_{0q}+\frac{\omega L_d i_{0d}+\omega\psi_f}{R_c}\right)^2\right] \qquad (8)$$

$$P_{\text{motor loss}}= P_{\text{iron}}+P_{\text{copper}}$$

Table 3. Properties and price of PM materials [30]

Property	Alnico	Ferrites	Samarium cobalt	Neodymium
Remanence(Br, T)	0.71-1.31	0.22-0.42	0.81-1.15	1.01-1.39
Coercitive force(Hc, kA/m)	36-144	51-289	482-841	759-1031
Maximum energy product,$(BH)_{max}$, kJ/m^3	10.5-71.6	8.32-31.9	131-241	221-338
Electric resistivity(Ω/cm)	(51-78)*10^{-6}	1*10^{-6}	(53-87)* 10^{-6}	159*10^{-6}
Maximum service temperature(^{0}C)	451-552	803	300-350	150
Density(g/cm^3)	6.8-7.3	4.8	8.41	7.42
Price, USD/kg	59	72	100.01	75.05

B. Induction Machine (IM)

Along with the DC machine, induction machines with squirrel-cage rotors are among the most technically complex machines, but they have a higher power density and efficiency [31]. Copper loss is the most common type of loss in IM machines. Copper losses are limited as a result of the decreased magnetization current in the area of field weakening, and the IM provides a wide speed range with rather an acceptable efficiency at high speeds. When compared to PMSMs, the needed magnetization current and copper losses in the rotor limit efficiency in the nominal speed range. The heating of the rotor as a result of the losses is negative, as it necessitates cooling and limits overload capacity. Moreover, a tiny air gap is required to reduce magnetization current, but this requires tighter permissiveness during manufacturing, which raises production costs.

C. Switched Reluctance motor (SRM)

Because of its simple and robust construction, ability to operate at extremely high speeds, and hazard-free operation, SRM is getting a lot of attention as a possibility for electric propulsion in EVs and hybrid electric vehicles (HEVs) [32]. One of the first SRMs was developed and built for EV application [33] because of these qualities. The efficiency of the drive was given a lot of thought when manufacturing this SRM. Later, in [34], an optimized SRM design approach for EV application was reported. To examine the dynamic and steady-state performance of each SRM design considered in this study, the static torque and flux-linkage characteristics as functions of stator current and rotor position are required. The analysis is complicated by the SRM's nonlinearity due to its saturation zone of operation. Several nonlinear analytic models of SRM are proposed in the literature [35-38] to get static data.

D. PM Brushless DC Motor (PMBLDC)

In many aspects, PMBLDC motors are similar to synchronous motors. Induction motors have "slip," but PMBLDC motors do not. PMBLDC motors are well-suited for EVs because of their high power densities, strong speed-torque characteristics, high efficiency, wide speed ranges, and low maintenance. PBLDC motors are synchronous motors [39]. This means that the magnetic fields produced by the stator and rotor have the same rotational frequency. Hall effect sensors or coil EMF measurements are used to gather information on rotor motion [40]. The PMBLDC motor [41] is made up of a permanent magnet rotor and wire-wrapped stator poles. Most PMBLDC motors have three stator windings arranged in a star. Each winding is made up of interconnecting coils. A winding is formed by keeping one or more coils in the slots and connecting them. To generate an even number of poles, each of these windings is dispersed around the stator's periphery region. PMBLDC motors are a kind of advanced energy-saving electrical machine with benefits such as small size, lightweight, high efficiency, low rotary inertia, and high control precision [42-44].

Table 4. Characteristics Comparison of various motors used in EVs [45-47].

Characteristics	SRM	PMSM	PMBLDC	IM
Reliability	Very high	High	High	Very high
Efficiency	Medium	Very high	Very high	Medium
Controllability	Medium	High	High	Very high
Technology maturity	High	High	Medium	Very high
Maintenance	Low	Low	Low	Low
Power density	Medium	Very high	Very high	Medium
Noise level	High	Very low	Low	Very low
Cost	Low	Medium	High	Very low

Table 5. Motor characteristics at speed 1500 rpm

Motor	Iron loss (W)	Copper loss (W)	RMS current density (A/mm^2)	Torque (NM)	Efficiency(%)
PMSM	198.2	4329	15.8	303	91.7
IM	147	8592	12.3	298	83
PMBLDC	189	5328	11.9	301	89.3
SRM	413	7655	21.8	289	85.2

Table 6. Motor characteristics at speed 6000 rpm

Motor	Iron loss (W)	Copper loss (W)	RMS current density(A/mm^2)	Torque (NM)	Efficiency (%)
PMSM	949	228	3.71	56.8	96.3
IM	443	731	4.61	51.3	93.6
PMBLDC	848	326	3.48	43.9	91.2
SRM	4096	315	5.03	49.6	89.3

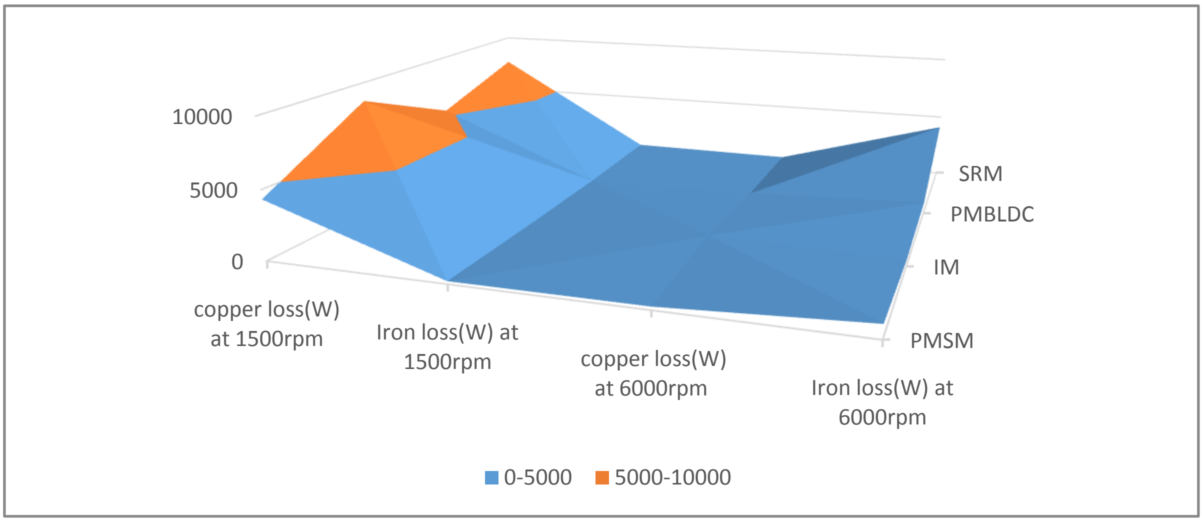


Figure 9. Iron loss and copper loss for different types of motor at 1500rpm and 6000rpm

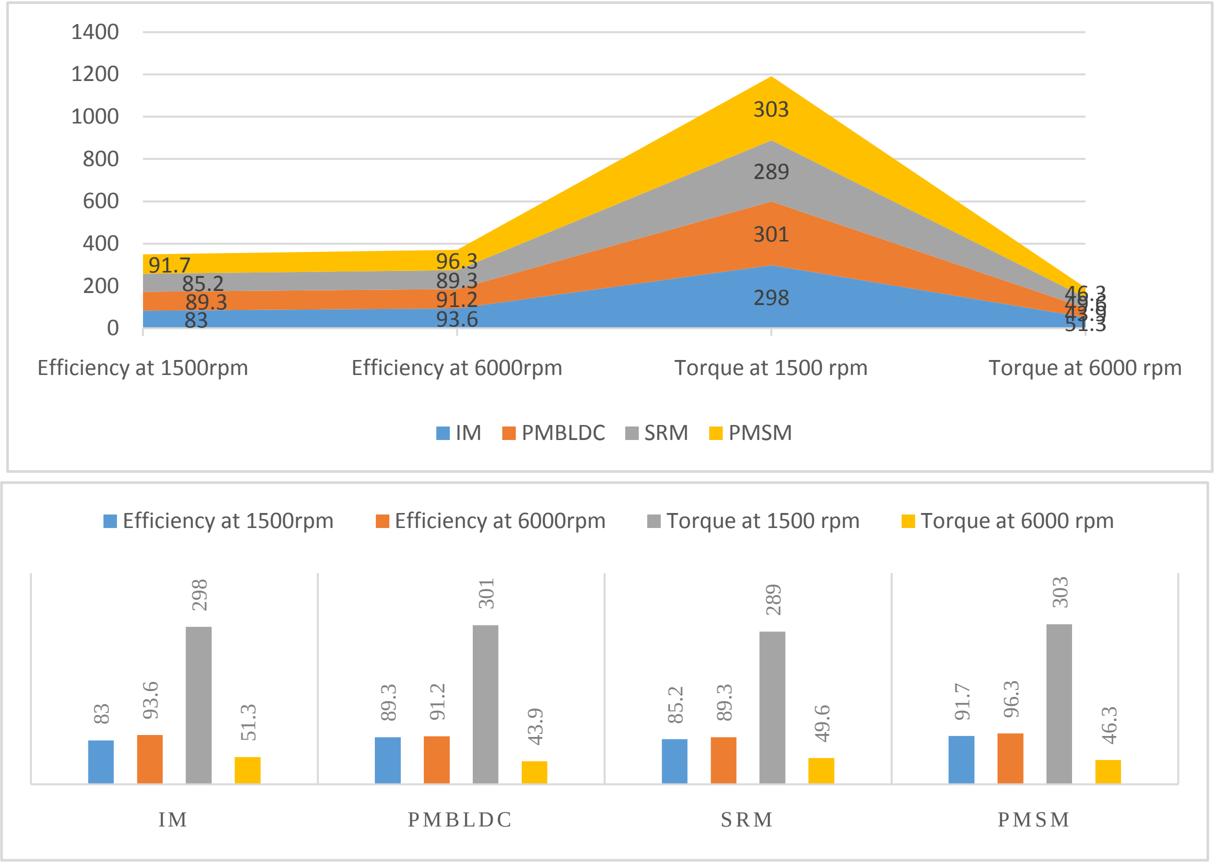


Figure 10. Efficiency and torque for different types of motor at 1500 rpm and 6000 rpm

Table 7. Representative production EVs and their key electric motor characteristics such as torque and top speed.

EV Models	Motor type	Maximum power (kW)	Maximum torque (Nm)	Top speed (km/h)	Battery capacity (kWh)	Drive type	Year
Audi e-tron sportback 50 quattro [48]	EM+EM	230	540	190	71.0	AWD	2022
Mercedes EQA 250+ [49]	EM	140	385	160	73.9	FWD	2022
Jaguar I-PACE EV400 [50]	-	294	696	200	90.0	AWD	2022
Hongqi E-QM5 [51]	PM	100	431	-	56.0	FWD	2021

Tata tigor [52]	PM	55	170	120	26.0	FWD	21-22
Mahindra E-verito[53]	IM	31.31	91	86	18.55	FWD	2021
Renault Jiangling Yi [54]	PM	110	225	140	41.0	FWD	2021
Tata Nexon [55]	PM	96.1953	245	120	30.2	FWD	21-22
Tata Nexon EV [57]	PM	85	200	-	30.2	FWD	2020
Honda e advance [56]	-	113	315	145	35.5	RWD	2020
Porsche Taycan Cross Turismo [56]	-	440*	900*	250	93.4	AWD	2020
Kia-e-Soul [56]	PM	100	395	156	64.0	FWD	2020
Volkswagen id.3 [56]	PM	100	275	160	58.0	RWD	2020
Kia e-Niro [58]	PM	150	395	167	67.5	FWD	2019
MG eZS [59]	PM	110	350	-	44.5	FWD	2019
BJEV EX3 [60]	PM	160	300	150	61.3	FWD	2019
BYD S2 [61]	PM	70	180	101	40.62	FWD	2019
Smart EQ fortwo [62]	PM	60	160	130	17.6	RWD	2019
Volkswagen e-golf [56]	PM	100	290	150	35.8	FWD	2019
Mercedes EQC [63]	IM+IM	300*	760*	180	80.0	AWD	2019
JAC iEVS4 [64]	PM	110	330	150	66.0	FWD	2019
Tesla Model 3 [65]	IM+PM	147+211	639*	260	75.0	AWD	2018
Renault ZOE [66]	SynC	80	225	135	44.1	FWD	2018
Hyundai Kona Electric [67]	PM	150	395	167	39.2	FWD	2018
Jaguar I-PACE [68]	PM+PM	147+147	348+348	200	90.0	AWD	2018
Roewe Marvel X [69]	3 PMs	222*	665*	170	69.9	AWD	2018
Audi e-Tron [70]	IM+IM	125+140	247+314	200	95.0	AWD	2018
JAC iEV7L [71]	PM	50	215	110	35.0	FWD	2017
BJEV EC180 [73]	IM	30	140	100	20.3	FWD	2016
BMW i3 [74]	PM	125	250	150	22-33	RWD	2016
Geely Emgrand EV [75]	PM	120	250	140	41.0	FWD	2016
Tesla Model SP85D [72]	IM+IM	165+350	931*	250	60.0	AWD	2016
Chery eQ [69]	PM	41.8	150	100	32.0	FWD	2015
Changan Benben EV [77]	PM	55	170	125	32.2	FWD	2014
Zinoro 1E EV [76]	PM	126	170	130	24	FWD	2014
Fiat 500e [78]	PM	83	200	141	24.0	FWD	2013
Mercedes SLS [79]	4PMs	552*	1000*	250	60.0	AWD	2013
Roewe E50 [69]	PM	52	155	130	22.4	FWD	2013
Nissan Leaf [80]	PM	80	280	145	24.0	FWD	2012
BYD e6 EV [79]	PM	90	450	140	82.0	FWD	2008
Tesla Roadster [81]	IM	185	370	200	53.0	RWD	2008

Notes. AWD: All-wheel drive; FWD: Front-wheel drive; RWD: Rear-wheel drive; SynC: Synchronous machine with rotor coil; *: combined value.

III. DISCUSSION AND CONCLUSION

In this paper, 5-level cascaded MLI with different types of an electric motors are analyzed. The simulation result of 5-level inverter THD had been decreased using energy storing element which connected in a particular manner. The THD without this energy storing element is 29.04% *(shown in figure 5)*. After using the energy storing element THD becomes 2.86% *(shown in figure 7)*. The performance of EVs increased by the reduction in THD and analyzed the various type of motors with the multilevel inverter-fed system has better torque performance and lesser torque ripple. This paper analyzed different types of electric motors (PMBLDC, PMSM, SRM, IM). After theoretical analysis, we concluded that the PMSM is a highly efficient motor with high torque at various speeds. The efficiency of PMSM at 1500 rpm is 91.7% *(shown in table 5 and figure 10)* which is the highest in all types of electric motor and the efficiency of PMSM at 6000 rpm is 96.3% *(shown in table 6 and figure 10)* which is the highest at this speed in all types of motor. From the torque point of view, PMSM is providing the good torque in their group *(figure 10 torque at 1500 rpm & torque at 6000 rpm)*. From the perception of losses, the PMSM has the lowest loss in the group of all types of motor. So, the overall performance of the electric vehicle will improve with a 5-level inverter with PMSM.

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Annexure

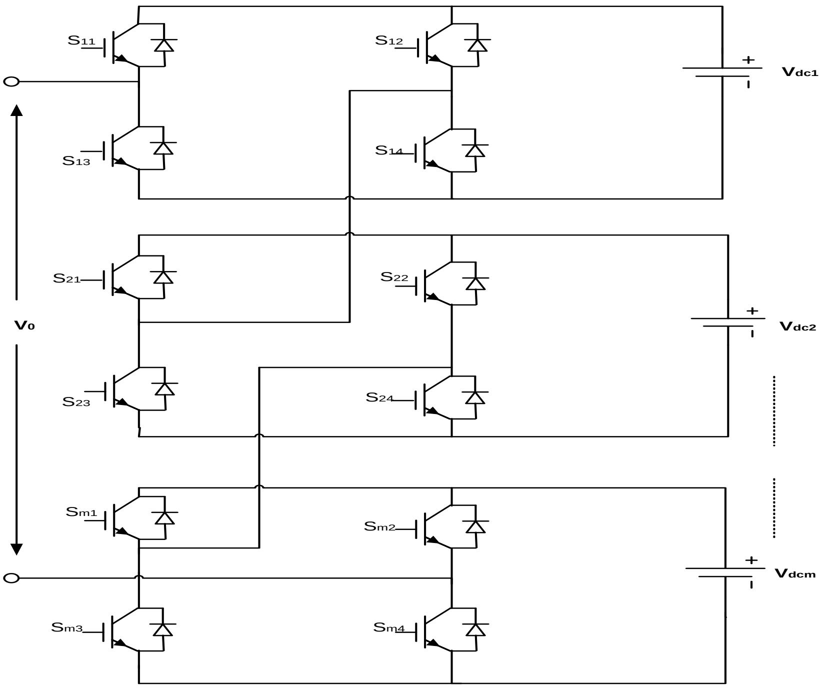

Figure 1.Single phase cascaded multilevel h-bridge inverter

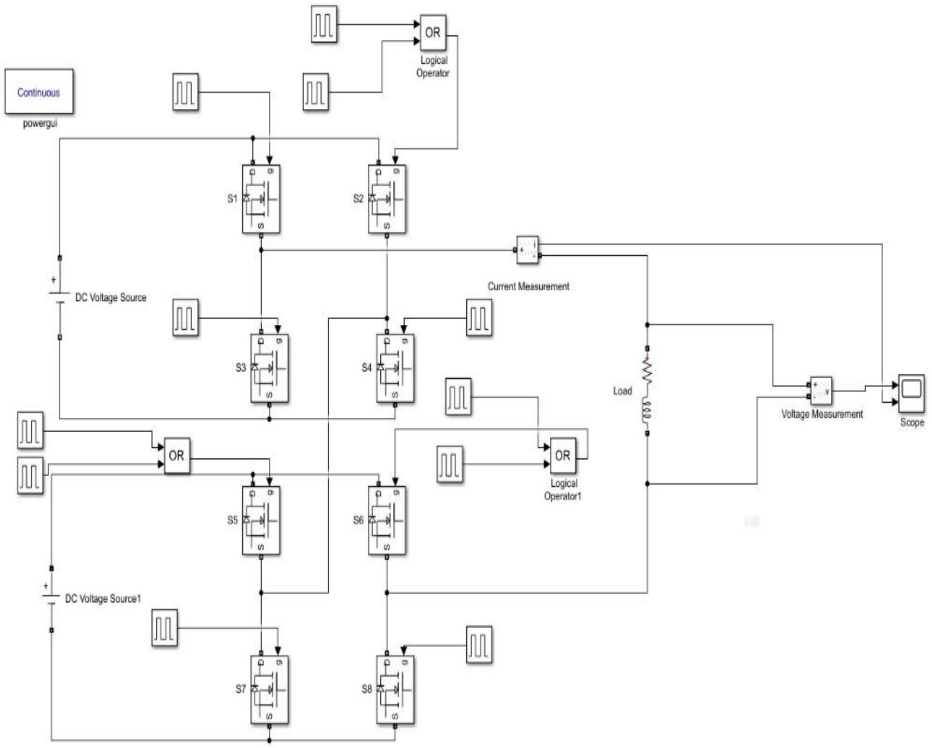

Figure 2. MATLAB model for 5- Level cascaded inverter without filter

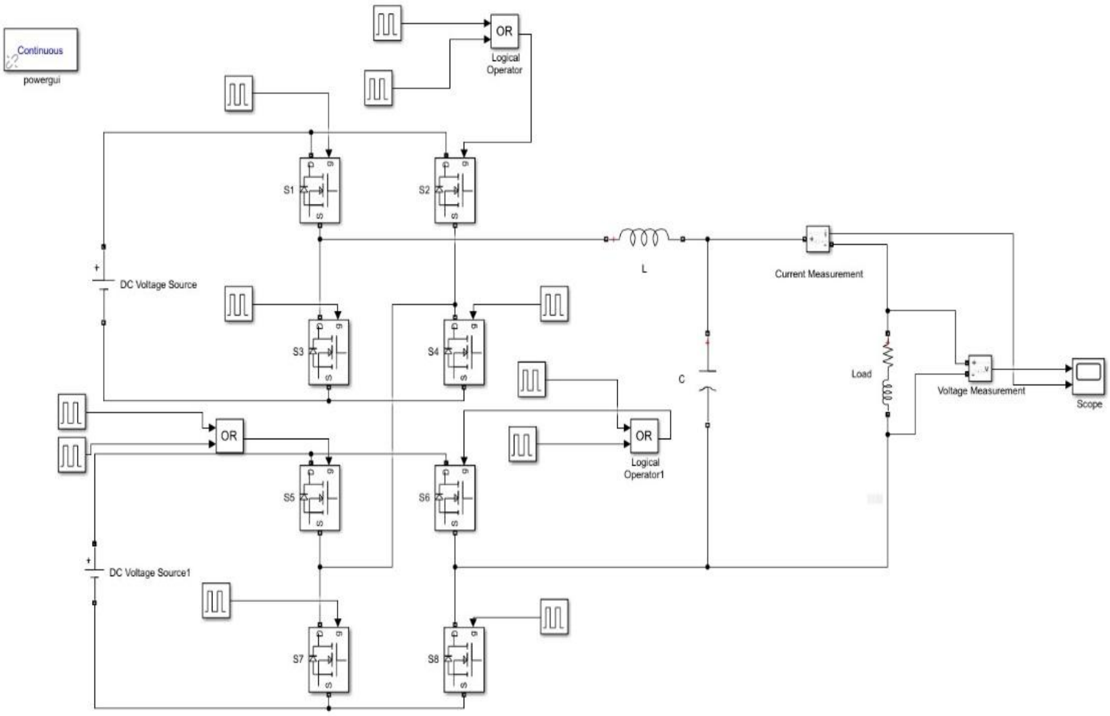

Figure 3. MATLAB model for 5- Level cascaded inverter with filter

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